Why Missile Defense Won't Work

TECHNOLOGY REVIEW

APRIL 2002

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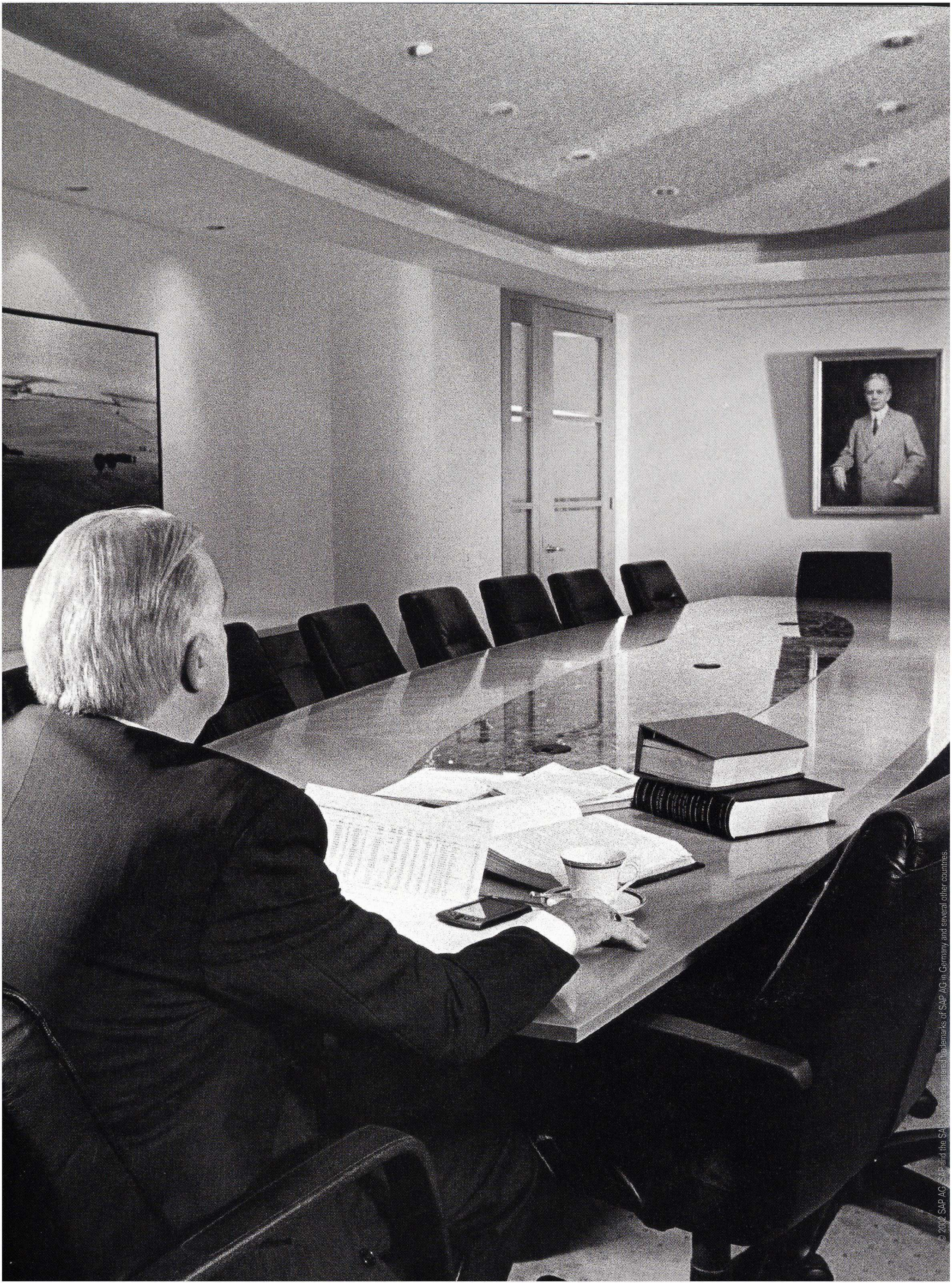

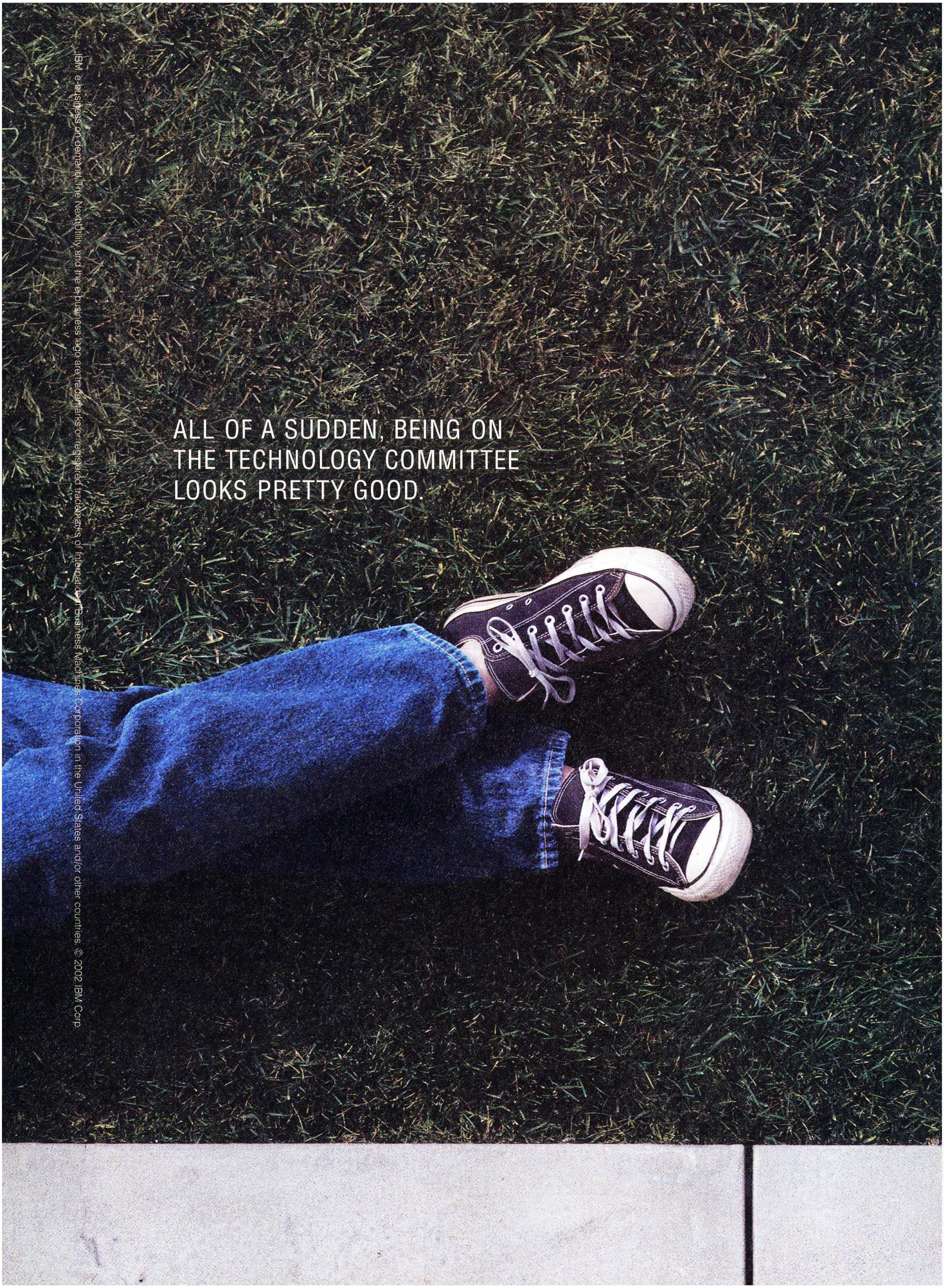
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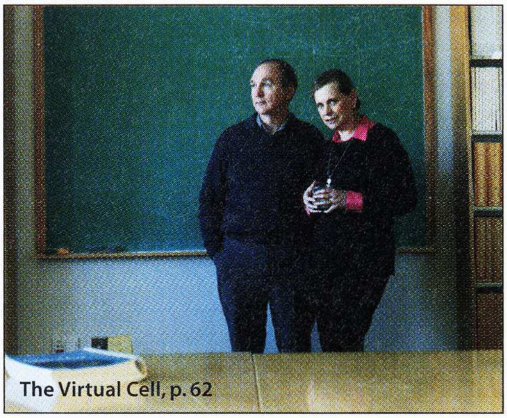
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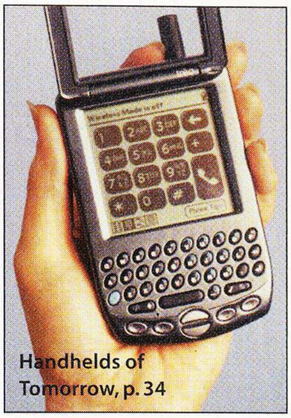
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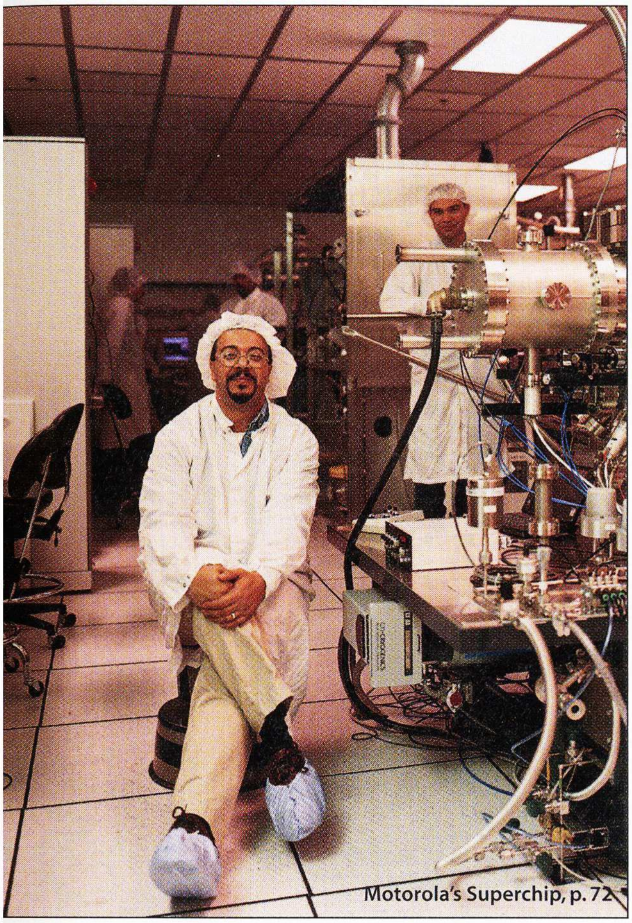
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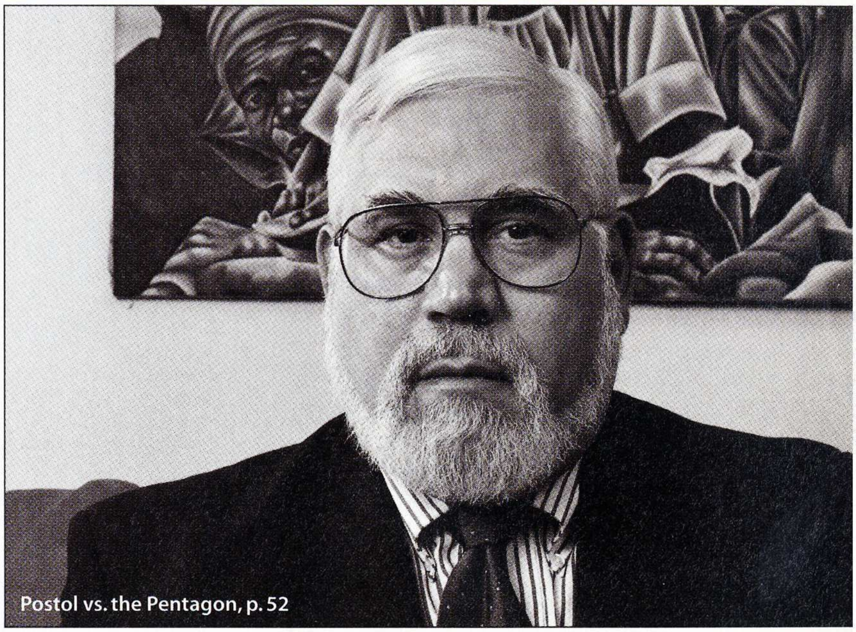
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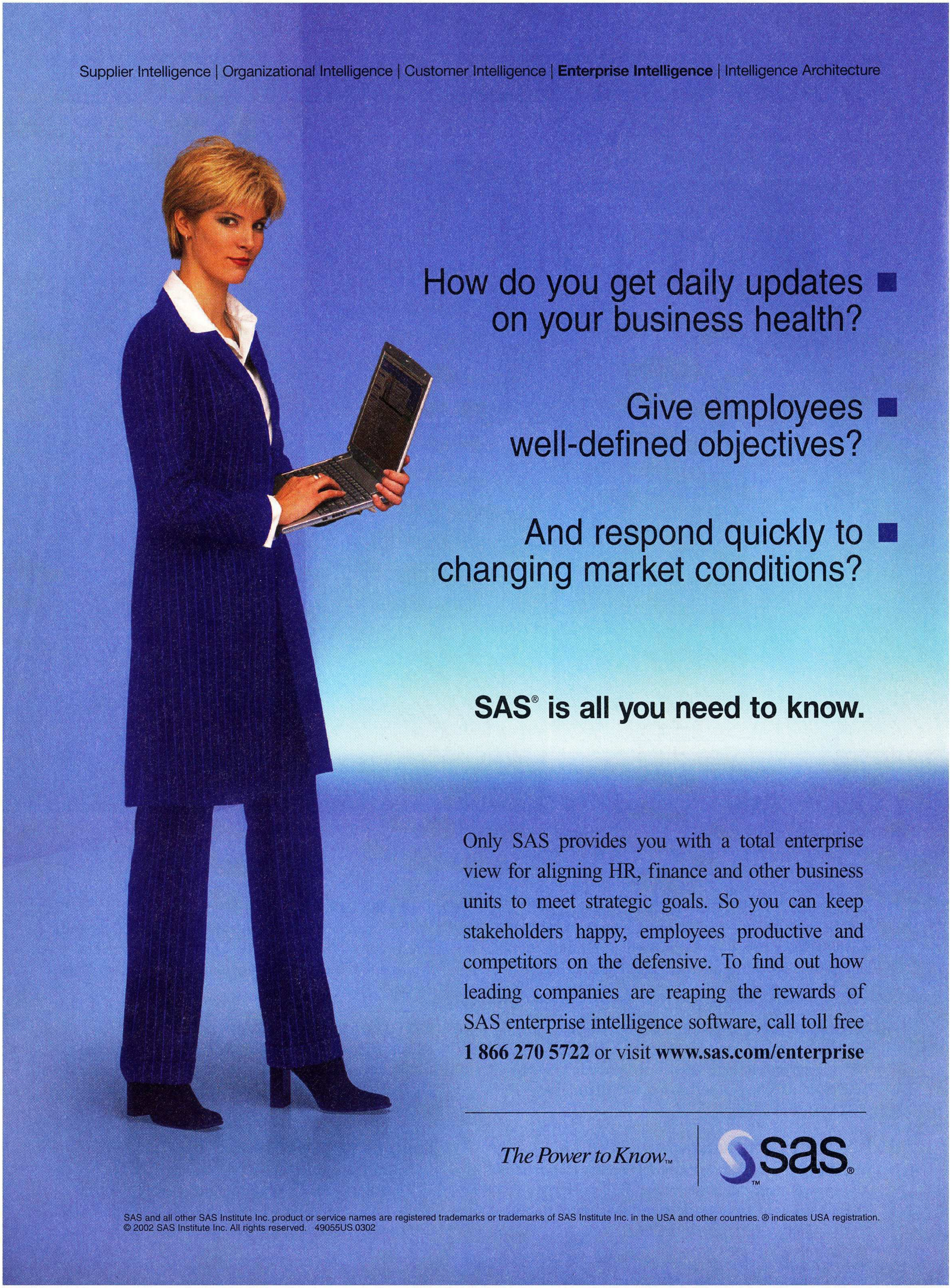
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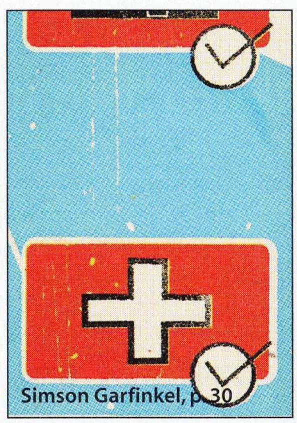
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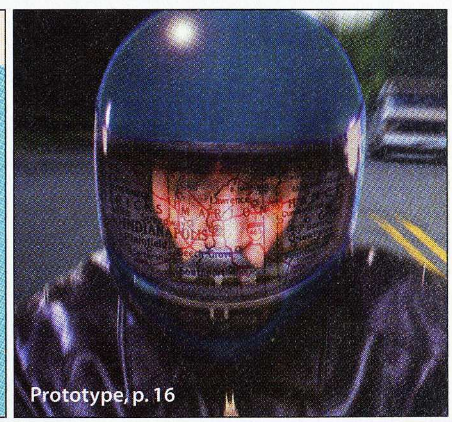
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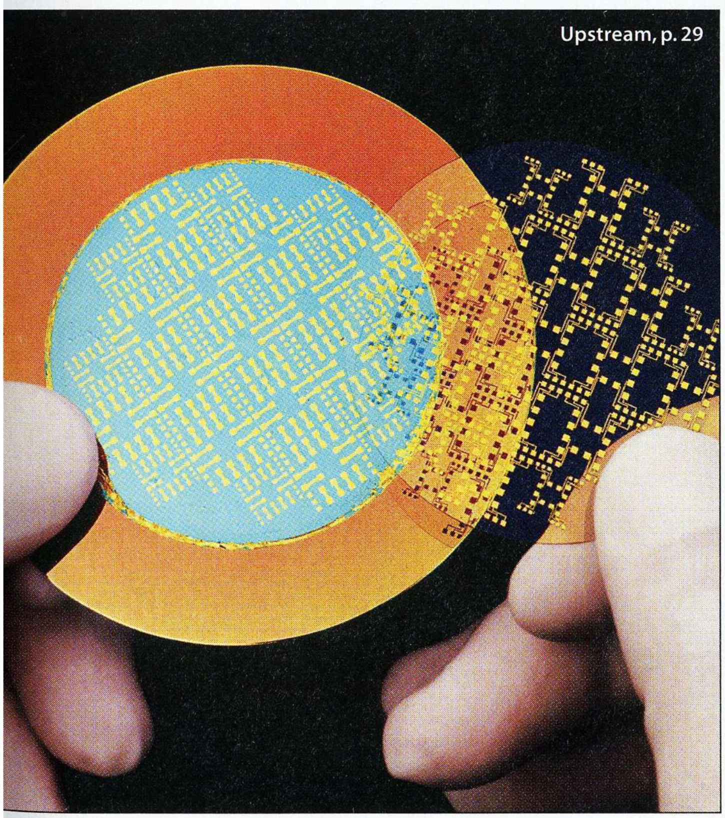
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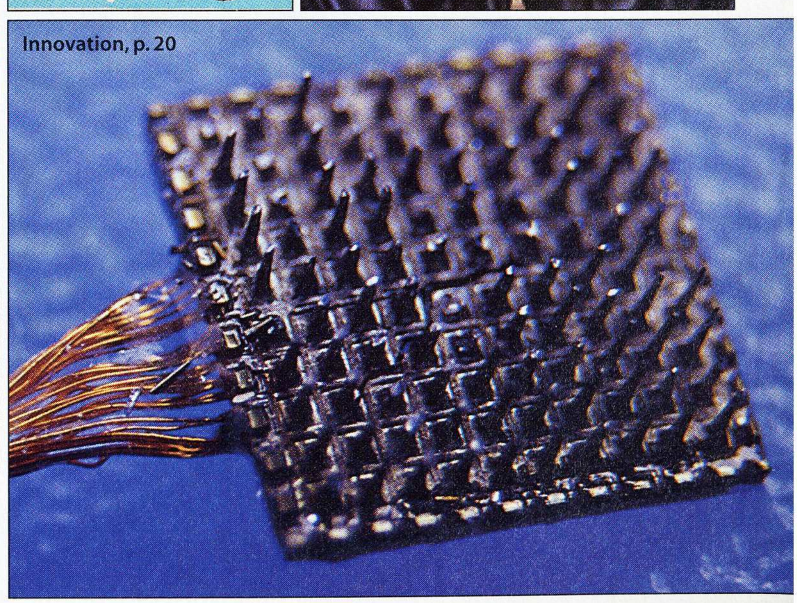
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AN INVITATION TO THE PENTAGON

I have an invitation for our nation's top defense officials, those responsible for the development of our current missile defense effort (now called NMD, for "national missile defense"). But before we get there, let me describe the context for this invitation, which is established in two dramatic articles in this issue of *Technology Review*.

Both articles focus on a controversy over missile defense that has an MIT professor at its center. Theodore Postol, professor of science, technology and national security, is a prickly, fractious man who irritates and accuses almost everyone who crosses his path, as contributing writer Gary Taubes acknowledges in his article "Postol vs. the Pentagon," which begins on page 52 of this issue. There's no question that Ted Postol's "people skills," as the jargon has it, are not his strong suit.

But there's also no question that he's well placed to cast a cold eye on the nation's missile defense effort, which has, despite skepticism from the science and engineering community, stubbornly refused to succumb since it was conceived as the Strategic Defense Initiative in the long-ago Reagan era. Postol was trained in physics, and he has a distinguished background in government and academia as an analyst of national security issues. Sidney Drell, former director of the Center for International Security and Arms Control at Stanford University and Postol's former boss there, calls Postol "a unique resource for doing hard-nosed, accurate, reliable and important technical analysis of military systems." Drell adds that he's never known Postol to be wrong on an important security issue.

One big issue on which Postol appears to have been dead right is the inadequacy of the Patriot missile system. During the Gulf War the Pentagon trumpeted the success of the Patriot in shooting down Iraq's Scud missiles. The official line was that the Patriot's prowess showed the viability of the concept of missile defense. The first President Bush gushed in a 1991 speech, "Patriot is proof positive that missile defense works."

As Taubes describes, Postol became the skunk at the Patriot party. Using the Pentagon's own videotapes, which had been broadcast on television, he showed that the Patriot could not have knocked out nearly as many Scuds as its proponents claimed. In a reverse version of the story of those other Patriots (the Super Bowl champions), the missile quickly went from first to worst. Everyone, except perhaps the missile's maker, Raytheon, eventually conceded that the Patriot was a Gulf War bust.

Now, as Taubes tells us, Postol is up to his old tricks. This time he's taking aim at a series of tests of the current missile shield. As in the case of the Patriot, an early test of the current system, conducted over the Pacific in 1997, was proclaimed by the Pentagon to be a success that vindicated the concept of missile defense generally. An antimissile missile, known in defense lingo as an "exoatmospheric kill vehicle," flew by a cloud of decoys surrounding a dummy warhead. According to the official version, the kill vehicle's sensors picked the "warhead" out from among the decoys—a key task for any defense system that aims to destroy warheads after they've already separated from their booster rockets, as the current one does.

Not so fast, says Postol. Spurred on by the work of whistleblower Nira Schwartz—a former employee of TRW, a firm that developed key missile defense technology—Postol conducted his own analysis. He concludes that the 1997 trial was actually a failure and that the data from that experiment and subsequent ones have been manipulated. He lays out the evidence in an article of his own, "Why Missile Defense Won't Work," that begins on page 42.

Technology Review invites the Pentagon to debate missile defense with Ted Postol in a public forum provided by the magazine. The issues are too important to be settled behind closed doors.

Not that Ted Postol is opposed to any conceivable form of missile defense. On the contrary, he believes a more modest system—short-range rockets that aim to destroy missiles shortly after launch, while they're still in the earth's atmosphere and the warheads haven't yet detached—is feasible. And he believes, as he writes in his piece, that the United States should contemplate deploying such a system, which, he argues, would be far less destabilizing, geopolitically, than the one we're working on now. But he argues forcefully that the current system does not and cannot work and that its deployment will make the world a significantly less safe place to live.

Here's where we return to my invitation. I find Postol's credentials impressive and his technical arguments plausible. Still, there are always two sides to every story, and on an issue as critical as this, the public has the right to hear both sides openly debated. Therefore I am extending an invitation to the Pentagon to send a spokesperson well versed in missile defense to debate the merits of the current version of missile defense with Ted Postol. *Technology Review* will find a venue and I will be happy to moderate the discussion personally. I feel sure that other media, including radio and television, would find such a dialogue newsworthy.

Indeed, it *is* newsworthy. Missile defense, like war, is too important to be left to the generals. It is a subject too significant to be debated behind closed doors or in classified documents. The health and safety of our society depend on our willingness as citizens to assimilate important scientific and technical issues and make up our own minds about them. I hope those responsible for the development of our missile defense system will agree. *—John Benditt*

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Q&A

Kai Flore, CIO,
Fujitsu Siemens Computers

How did Fujitsu Siemens Computers prepare for the future in its supply chain? As Europe's leading computer company we operate in all key markets across Europe, the Middle East, and Africa and offer one of the world's most complete product and solution portfolios. What is more, we are the only major company developing and manufacturing IT products in Europe. We had to prepare for the increasingly fast pace of innovation and dramatic seasonal fluctuations of the PC and server market. On the other hand, expectations of our European customers have grown, and they demand complex preconfigured systems to be delivered within days. This means sales forecasts need to be exact and inventory levels need to be kept to a minimum.

HOW

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R. Bruce Journey, bruce.journey@technologyreview.com

VICE PRESIDENT AND GENERAL MANAGER
Martha Connors, martha.connors@technologyreview.com

VICE PRESIDENT, SALES AND MARKETING
Kate Dobson, kate.dobson@technologyreview.com

CORPORATE

BUSINESS DEVELOPMENT MANAGER
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FEEDBACK

LETTERS FROM OUR READERS

ENERGY FUTURES

John Benditt's editorial "Energy Futures" (*TR* January/February 2002) touches on an important issue: our increasing oil imports, largely due to increasing road transportation by an increasing population. But I am less disturbed about it than he is. Oil is fungible. If Middle Eastern oil exports are interrupted, world supply is reduced and the price will certainly rise. But the impact for the United States will be minor: another dollar added to the price of gasoline, but a negligible rise in electric-power costs. Why do we then feel compelled to use our military to defend oil wells in the Middle East?

If Congress really wants to decrease reliance on oil imports, the obvious solution is to raise gasoline taxes. New energy technologies are bound to appear as fossil fuels become depleted and more costly. The real question is whether these developments require government support or can be left to the private sector.

S. Fred Singer
Department of Environmental Sciences
University of Virginia
Charlottesville, VA

OIL TROUBLES

Charles C. Mann's article ("Getting over Oil," *TR* January/February 2002) doesn't give a complete picture of the true cost of oil. Mann mentions externalities in the form of environmental damage, but he overlooks the taxpayer money devoted to the defense of oil reserves in the Middle East. If there were a way to reflect those costs at the gas pump, we would certainly become more interested in conservation and alternative energy. We already pay the price, but indirectly, which suits both the politicians and the public.

Jack Atkins
Albuquerque, NM

As coauthor of the book *The Limits to Growth*, which Charles C. Mann cites in his article, I would like to make the following clarifications. Contrary to Mann's implication, our book did not conclude that "the world was going to run out of petroleum by 1992." Nor does the book mention the possibility of an "energy catastrophe."

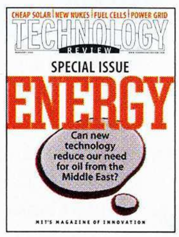
Dennis Meadows
Institute for Policy and
Social Science Research
University of New Hampshire
Durham, NH

Charles C. Mann responds:
It is true that Meadows's book did not use the phrase "energy catastrophe." Those were my words. However, the authors do paint a picture that could lead one to such a conclusion. The 1972 book did state that if petroleum consumption were to continue to rise at its then present rate, reserves would be exhausted in 20 years—that is, in 1992. The authors asserted that this gloomy forecast would hold "regardless of the most optimistic assumptions about undiscovered reserves, technological advances, substitution or recycling."

PATENT SUSPENSE

Seth Shulman's criticisms of the drug company Bayer for its handling of the antibiotic for anthrax, Cipro, are unjustified ("Protecting People above Patents," *TR* January/February 2002). Asking the federal government to suspend patent law during a national emergency is asking for theft. Shulman proposes that a country fighting for its values abandon those values when times are tough. The war on terrorism may be long, and it will require new technologies. Without the protection of patent law, the companies that develop these new technologies will have little incentive to contribute to one of the few areas of the economy that may grow in the near future.

Joseph M. Cadrin
Yorktown, VA



"If the cost of defending oil reserves in the Middle East were reflected at the gas pump, we would become more interested in conservation and alternative energy."

SAFE NUKES?

The pebble bed reactor described in David Talbot's article "The Next Nuclear Plant" (*TR* January/February 2002) is indeed far safer than those currently in use in the United States. However, proponents of this type of reactor incorrectly argue that its improved safety eliminates the need for a containment building. The failure to have a containment building at Chernobyl caused tremendous human tragedy. In fact, a common theme among all past nuclear-plant failures is that the designers didn't anticipate a potential failure or thought the possibility was too remote. The containment building isn't there to address the accidents engineers can predict. It's there to keep the accidents engineers don't predict from turning into tragedies.

Jim Staudt
North Andover, MA

Correction: The article "Getting over Oil" misstated the U.S. contribution to global carbon dioxide emissions. Of the total of 5.6 billion metric tons of carbon dioxide pumped into the atmosphere in 1999, about a quarter came from U.S. energy use. Also, the Signal Hill oilfield pictured on page 35 was misidentified; it is located in California.

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MOVIES ON THE SMALL SCREEN

Makers of digital organizers have long promised that we'll be able to use their portable gadgets to view premium video content, such as current films and television shows. Movie studios and other copyright owners have not been terribly cooperative, though, holding back their content and citing the lack of reliable antipiracy technology. Now there's a way around this impasse: this spring, San Francisco startup Mazingo Network is launching the first system that delivers copy-protected video to handhelds. As a result, people will finally be able to watch copyrighted movies and TV shows on the devices' small screens. Video playback is "one of the best features of the Pocket PC," says Bill Dettering, Mazingo's founder and chief technology officer.

The system—designed for Pocket PC devices from Compaq, Casio and others—is built around software that adds decryption capabilities to PocketTV, a widely used (and free) program for viewing video on a mobile device. Mazingo's subscription-based service transmits both video files and a decryption certificate to a Pocket PC. If the certificate matches an ID embedded in the device, playback begins. This approach wasn't possible until recently, since the the previous generation of Pocket PC devices lacked unique IDs.

HIGH-TECH MEDIC

An array of acoustic sensors that can be worn around the neck to pick up breathing patterns and heartbeat rates could help monitor soldiers' physiological condition on the battlefield. The prototype sensors, under development at the U.S. Army Research Laboratory, consist of microphones embedded in gel-filled pads. The gel, whose density and sound speed match those of human tissue, optimizes the conduction of sound from within the skin to the sensor. It also blocks out ambient noise (likely to be very loud on a battlefield). By listening to the sound of blood flow and respiration, the sensor monitors heart and breath rates, blood pressure, coughing, vomiting and other symptoms of distress. The sensors would transmit their readings to a remote receiver via a wireless communications device. The sensors can also be worn on the wrist or a headband *(photo)*, making them less cumbersome than vests that are also under development for similar monitoring applications. The sensors remain several years from battlefield readiness.

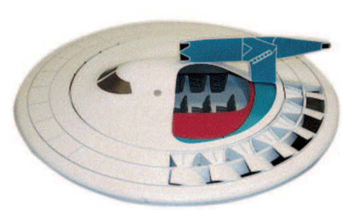
MIND YOUR MEETINGS

Some of the best insights hatched at brainstorming meetings get lost in the shuffle for lack of supporting information. Eric Brown and colleagues at IBM's Watson Research Center are working on software called Meeting Miner that could patch these productivity leaks.

First, existing speech recognition software records freshly hatched ideas as they are voiced. Next, new text analysis technology gauges the ebb and flow of words and determines when a chunk of a discussion represents a larger topic. The program then uses keywords to search for related information. Participants in a chip design meeting, for instance, might rely on Meeting Miner to flag conflicts in a patent database. Brown is working to adapt the system into a help desk aid for service reps who need transcriptions of complaints and answers to customer problems.

IDENTIFIED FLYING CONCEPT

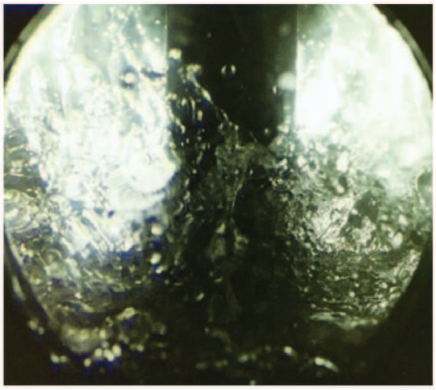
As the U.S. Department of Defense solicits designs for aircraft that can take off vertically, one option is—yes—a flying saucer. In the conceptual design by Go Aircraft of Long Beach, CA, a round fuselage rides on a single large fan whose blades reach the perimeter of the circular craft. Jet engines are mounted on the fuselage; their thrust is routed through ductwork to the fan for vertical lift. Once clear of obstacles, the craft tilts to create forward thrust until finally all jet thrust is redirected rearward to achieve cruising speed. In theory, the craft has twice the range and cruising speed of the military's troubled tilt-rotor V-22 Osprey. Ron Sincavage, senior program manager for autonomous vehicles at Draper Laboratory in Cambridge, MA, says the concept "offers the potential for a highly agile and maneuverable system." A patent on the design is expected to be issued soon. However, says Go Aircraft president Gordon Ow, "It's not capable of outer-space travel."



Model of a 24-person flying saucer

COURTESY OF GO AIRCRAFT (FLYING CONCEPT); COURTESY OF U.S. ARMY RESEARCH LABORATORY (HIGH-TECH MEDIC); COURTESY OF POCKET PC FILMS AND MAZINGO (MOVIES)

ALL SHOOK UP

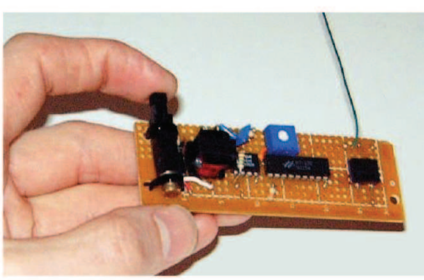


A new mixing technology based on low-frequency sound waves could save billions of kilowatt-hours for energy-hogging industries like chemical processing. It's a simple idea: a motor-driven bar vibrates in a chamber filled with liquids or gases, causing sonic waves that mix the materials *(photo)*. The low frequencies (typically below 100 hertz) are gentler than those of existing high-frequency sonic systems, which can damage delicate polymers. "It's like hitting a tuning fork and sticking it into a bucket of water," says Richard Talley, an engineer at Montec Research, the Butte, MT-based outfit that developed the system with funding from the U.S. Department of Energy. The first industrial-sized blenders using the low-frequency sonic technology will shorten mixing times by about 60 percent, according to the company. Montec is talking with companies in a number of industries dependent on mixing processes, including mining, waste treatment and petroleum.

FINGERTIP POWER

The batteries used in remote controls can be costly to replace—and they seem to run out of juice at the most inconvenient times. MIT Media Lab researchers Joseph Paradiso and Mark Feldmeier have devised a way to eliminate this hassle: a batteryless controller powered solely by the energy that goes into pressing its buttons.

The control *(photo)* contains a piezoelectric material that produces a voltage pulse when compressed. This electricity powers a wireless transmitter that can send a digital code more than 20 meters. The researchers have demonstrated this concept in a keyless car-entry remote. The same technology could also replace the batteries in TV remote controls. Products incorporating the controller could be on the market within two years.



HELMETS FOR HOGS

They swerve in and out of traffic, find parking spots lickety-split and emit an unmistakable aura of cool. But for bikers on their Harleys, it's a trickier affair to flip through CDs or fumble with a map. Enter a team of engineering students from the University of California, Berkeley, who have devised a motorcycle helmet endowed with voice-activated controls. The fully loaded helmet lets bikers speed dial their buddies, play Steppenwolf's "Born to Be Wild" or, eventually, download driving directions via GPS technology. "We want to provide the motorcyclist with all of the audio luxuries considered standard on a car, without the distracting controls," says team leader Dan Steingart, a materials science graduate student at Berkeley. The group strapped a Palm Pilot-sized server onto the motorcycle's frame to act as a universal control and equipped the helmet with a wireless transceiver and headset. The students are seeking venture capital funding.

DOCKING DESKS

Office work often involves idea sharing in one-on-one meetings. Researchers at the Fraunhofer Integrated Publication and Information Systems Institute in Darmstadt, Germany, have designed an electronic desk to facilitate such discussions. The "ConnecTable" *(photo)* is a horizontal, pen-writable display. When two of these tables are placed next to each other so that their edges touch, the display surfaces merge to create one big workspace. If one person draws a figure on her desktop, for instance, she can push it over to the other person's display by placing her pen on the figure and sliding it toward the other desk—much the way someone would slide a piece of paper across a conference table. Norbert Streitz, the desk's chief architect, says that the German furniture manufacturer Wilkhahn plans to bring the display table to market by year-end.

COURTESY OF AMBIENTE, GMD-IPSI; WIEGE, WILKHAHN (DOCKING DESKS); COURTESY OF MARK FELDMEIER (FINGERTIP POWER); VITO ALUIA (ILLUSTRATION); COURTESY OF MONTEC RESEARCH (ALL SHOOK UP)

THE PRICE IS RIGHT

Cheap! Cheap! Cheap! That's the hungry cry of the marketplace. Faster is nice. Better is good. But cheap, cheap, cheaper is what fuels growth and accelerates market share. Innovation dangles the tantalizing promise of more for less. "More for less" is what customers say they want. Just ask Intel about its next-generation microprocessor or Merck about the impact of generic drugs on its bottom line.

That's precisely why innovators have such a tortured relationship with price. Should they go for profit margins or for market share? Are they better off bundling in benefits or proffering discounts? How much of a premium can they command? What does it mean to say that the price is right?

These are excellent questions. Unfortunately, they have precious little to do with how people and organizations actually pay for innovation. The problem is a fundamental economic confusion between "price" and "cost." Most innovators honestly believe the "price" they charge represents the customer's "cost" of acquiring their brilliant innovations. It doesn't. Not even close. Genuine innovation almost always creates a disjunction between the price that's paid to acquire it and the actual costs of implementing it.

Customer cost—more than innovator's price—is what really determines the success of innovative offerings. Software from Microsoft or San Mateo, CA-based e-business specialist Siebel Systems is stuffed with features and benefits customers may say they want. But it's clear that this kind of innovation-laden "bloatware" imposes unique costs of its own, as the overwhelming majority of customers use only the tiniest fraction of all that functionality. It is not worth the perceived cost in time and effort to use the rest: the cure is worse than the disease. Why do the smarter software companies continually invest in user interface design? Because ease of use reduces the real costs of adoption.

Viewed in this light, cutting prices becomes the laziest possible way for innovators to reduce customer cost. The challenge is to identify the complex of variables that customers use to assess their own acceptable costs. Would Amazon still be alive if it had consistently taken two weeks to ship books to its customers in its early days instead of providing next-day and second-day delivery gratis? If the Israeli company Mirabilis's ICQ instant Internet messaging service had become a conduit for disk-destroying viruses, would AOL have invested $400 million to acquire it? Of course not. Time, security and perception of risk are costs that innovators must abide. Too often, innovators prefer to focus only on the solutions their concepts attempt and ignore the new problems their products create.

These true-cost-of-innovation problems become acute at the organizational level, where human foibles become a factor. If a computer-aided design package is so powerful and easy to use that industrial designers and even, say, project managers can use it to reliably model new product features, the company's engineers may be very unhappy. The innovation undermines their power and expertise. The engineers may do everything possible to stifle its adoption. Similarly, supply chain software that empowers local product teams at the expense of global procurement managers may face corporate resistance. Organizational politics and cultural differences are costs, too.

The medical marketplace is swamped with competing innovative diagnostics and therapies that often pit radiologists against internists against surgeons. Health maintenance organizations are notorious for their Byzantine referral services and illogical accounting for emerging treatments. Pharmaceutical companies are constantly trying to determine whether their new drugs should be targeted to patients, doctors and/or the health-care providers who ultimately pay for them. Nothing better illustrates this fundamental gap between the economics of price and cost in innovation than a hospital bill for a novel cancer therapy, with its jumble of itemized prices for each separate specialist, drug and procedure. No one knows how to price the costs associated with adopting a treatment.

The era of "faster, better, cheaper" innovation is hitting the point of diminishing returns. Customer cost is what really determines an innovation's success.

The era of "faster, better, cheaper" innovation is hitting the point of diminishing returns. The lure of the "paradigm-busting breakthrough" that commands a premium price has proven chimerical. Market forces are driving companies to account for their real costs of doing business. The problem is—à la Enron's false partnerships—most companies that are pushing new innovations refuse to be honest about how their products' promise translates into measurable performance.

Adopting and adapting an innovation is a cost of doing business. The price of procuring that innovation is just one variable in the total cost equation. Innovators that compete on price, features and functionality are missing the trend. They need to understand the costs associated with how innovative features diffuse throughout their customers' organizations.

There are always two learning curves going on in innovation marketplaces: one where innovators figure out how to make the innovations faster, better and cheaper, and the other where customers and clients go beyond price to learn the real costs of implementing those ever faster, better and cheaper ideas. Innovators are usually overinvested in understanding their own learning curves and underinvested in learning about their customers. They'll pay a price for that mistake.

BRAIN POWER

Implanted electrodes could aid paralyzed patients

In a small lab at Brown University in Providence, RI, a rhesus macaque sits in a chair facing a computer screen, gripping the handle of a device that looks a lot like a sailboat's tiller. For the moment, the monkey uses this device as if it were a computer joystick to control a simple video game: a colored dot appears on the screen, and the animal moves the cursor to meet it. Once the animal gets good at the task, though, the researchers in the adjoining room will flip a switch and it will be signals straight from the monkey's brain, not the joystick's movements, that drive the cursor.

This eerie feat is possible because the researchers, led by Brown neuroscientist John Donoghue, have implanted a tiny array of electrodes in the monkey's brain. The electrodes intercept signals from individual neurons in the brain, and a specially developed computer algorithm translates these signals into trajectories and velocities for the computer cursor. The researchers' ambitions, however, extend way beyond video-game-playing monkeys. Their hope is that their brain-machine interface system will give patients paralyzed by spinal-cord injuries or neurodegenerative diseases new abilities to interact with the world around them—using nothing more than the power of their thoughts.

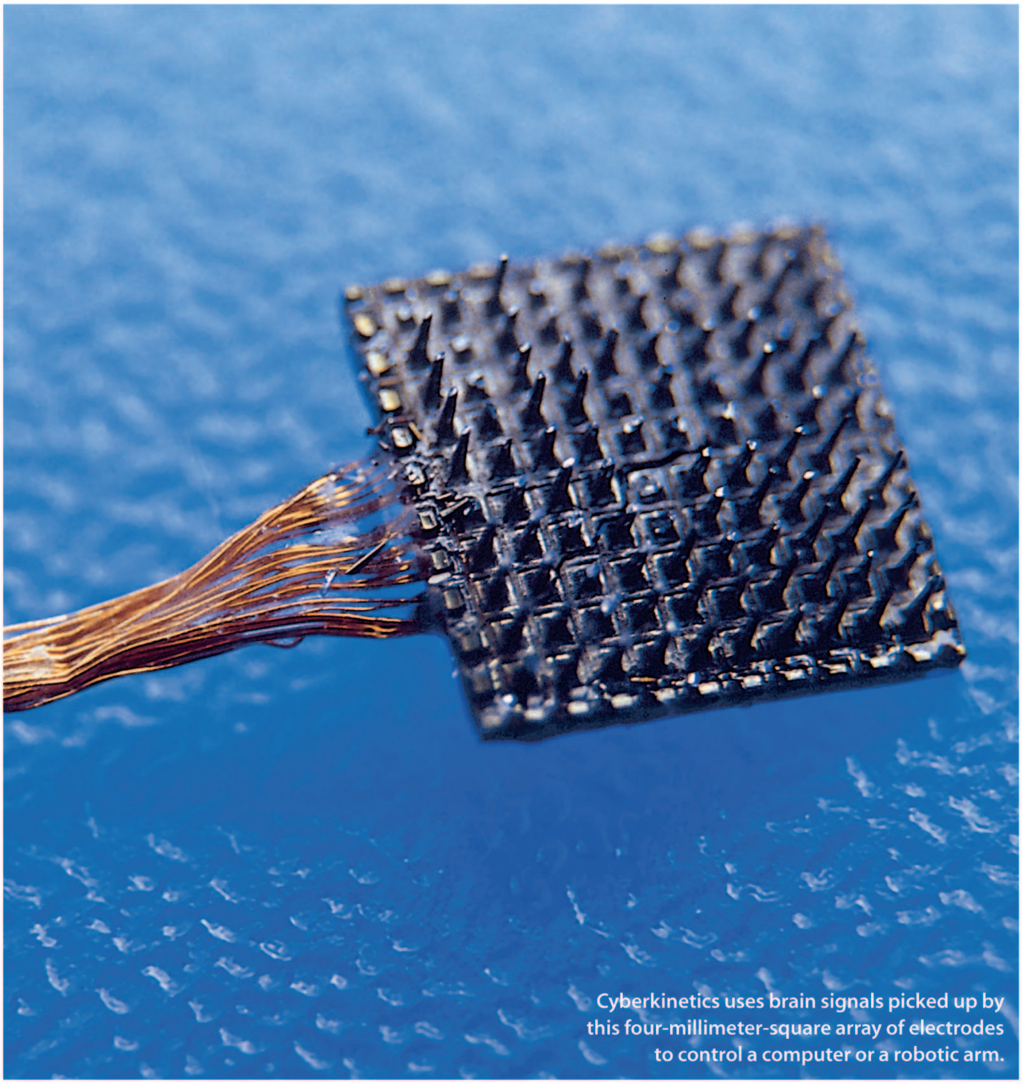
Donoghue and his team launched Cyberkinetics in June 2001 to pursue that vision. The company is one of the first to arise from research into brain-machine interfaces, which has so far been relegated mainly to a handful of academic labs around the world *(see "Brain-Machine Interfaces," TR January/February 2001)*. And while much development remains to be done, a system like Cyberkinetics' that taps directly into the brain could theoretically give paralyzed patients the means to control computers, robotic aids—and perhaps even their own muscles. Cyberkinetics aims to begin testing that theory in humans by the end of this year.

In the monkey studies that will pave the way for the human tests, the company—which includes cofounders Nicholas Hatsopoulos of the University of Chicago, Brown MD/PhD student Mijail Serruya and Gerhard Friehs, a neurosurgeon at Providence's Rhode Island Hospital—is focusing on the area of the brain that issues commands to the monkey's arm. Friehs starts by implanting a four-millimeter-square array of 100 electrodes in this region, which is located in the brain's outermost layer, about halfway between the ear and the top of the skull. After the surgery, a small bundle of wires snakes from the array through a hole in the animal's skull; those wires are plugged into a computer, feeding the electrical signals generated by neurons firing near each electrode into the machine.

Hatsopoulos sits at that computer as the plugged-in monkey practices a video game in the next room. The brain activity picked up by the array flashes across the screen as a jumble of hyperkinetic EKG-like graphs; rendered audible by the computer's speakers, brain signals snap, crackle and pop like Rice Krispies in milk. Hatsopoulos turns up the volume. "I never get tired of listening to that," he says. "This is really like reading the mind, eavesdropping on cells in the brain as the monkey's thinking of something." Pattern recognition software fishes the signal "spikes"—each representing a single firing of a single neuron—from the brain's background noise and correlates them with the position of the monkey's arm. "The amazing thing," says Donoghue, "is that very quickly you can get a sense of the neurons' activity and extract the hand's trajectory." Indeed, using only three minutes or so of data from the video game exercise, the computer can build a model capable of extrapolating the monkey's arm movements from the brain signal alone. Once the model is fine-tuned, the computer can use the brain signal to drive either a cursor or a robotic arm in real time.

Promising animal tests inspired the Cyberkinetics team to set its sights on human tests. "We already know so much," says Mijail Serruya. "Now let's put it to use."

Such promising results are part of what inspired the researchers to launch Cyberkinetics and push toward clinical



Cyberkinetics uses brain signals picked up by this four-millimeter-square array of electrodes to control a computer or a robotic arm.

FURNALD/GRAY

trials. “We already know so much; now let’s put it to use,” says Serruya. The participants in Cyberkinetics’ first human tests will be “locked-in” patients who, due to injury, stroke or neurological disease, are completely paralyzed, unable even to communicate except via subtle movements of their eyes. In those initial trials, the company will implant the electrode array, manufactured by Salt Lake City, UT-based Bionic Technologies, but the signal-processing hardware and power supply will remain outside of the body. If those first human tests bear out the promise of the monkey experiments, the company plans to further develop the technology to create an entirely implantable device.

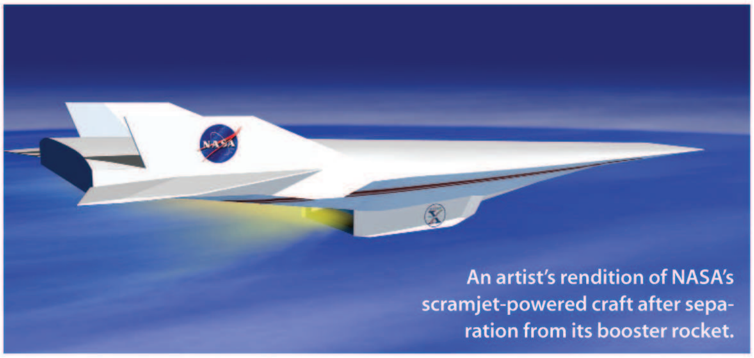
To date, only one company has conducted human tests of a brain-recording implant with the aim of helping restore function in paralyzed patients: Atlanta, GA-based Neural Signals. Instead of an electrode array, the company implants two “neurotrophic electrodes”—glass tubes containing tiny wires and a substance that encourages brain cells to grow into the devices. Neurologist and Neural Signals founder Philip Kennedy says the studies, begun in 1997, are going more slowly than he had originally hoped, but that the company should have some clear results by the end of the year. Cyberkinetics researchers believe, however, that implanting 100 electrodes instead of just two will make their system more robust and will allow it to gather more information from the brain.

While recent work in brain-machine interfaces is encouraging, some significant hurdles remain, says William Heetderks, head of the National Institutes of Health’s Neural Prosthesis Program, which helps fund brain-machine interface research. Perhaps the biggest challenge, Heetderks says, is building an interface between the recording device (a rigid piece of hardware) and the brain (a squishy mass floating in cerebrospinal fluid) that will maintain its precise position for decades, despite small movements of the brain. While both Kennedy’s and Donoghue’s devices represent progress on that front—Kennedy’s by encouraging cells to grow into the device and stabilize the connection, Donoghue’s by gripping the brain much as golf cleats grip wet earth—Heetderks thinks that some combination of approaches might ultimately be necessary. At this point, Heetderks says, human studies “may be still a little bit premature. But obviously that’s just one opinion.”

Greg Licholai, director of ventures and business development for the neurological division of Minneapolis, MN-based Medtronic, offers a different view. “This is truly a breakthrough in approaching neurological disorders,” Licholai says of Donoghue’s efforts. “I don’t think there’s going to be a problem recruiting patients, and the system has been well proven in an animal model. The only potential holdup is how long it takes them to draw up the documents and get FDA approval of those early-stage trials.”

Cyberkinetics’ business manager and only employee, Brown undergraduate Mikhail Shapiro, is helping the company look for the management team and funding it will need to get that paperwork in order and the human tests under way. Shapiro and the company’s founders all realize they will face both business and technological challenges, but they are also convinced that, as Hatsopoulos puts it, “This is real. This is really going to help people.”

—Rebecca Zacks



An artist's rendition of NASA's scramjet-powered craft after separation from its booster rocket.

SECOND CHANCE FOR SCRAMJET

SPACE | In its maiden test flight last June, a hypersonic plane developed by NASA veered off course and was destroyed. Despite the failure, the agency is now trying to breathe new life into its tests of the craft's novel jet engine, called a scramjet. NASA expects that future versions of the engine will serve as a low-cost way to get payloads into orbit by lifting space cargoes to nearly stratospheric altitudes before they continue their journeys on rocket power.

The X-43A, a 3.7-meter-long, unpiloted research vehicle, is the current focus of the $185 million effort. A conventional jet engine, with its spinning blades and turbines, would tear apart at lower speeds than those envisioned for the X-43A; but the scramjet has no moving parts. That means air can safely rush through it at many times the speed of sound, combusting with hydrogen fuel to boost the vehicle to hypersonic speeds (above Mach 5). Of course, conventional liquid-fueled rockets fly even faster, but they must carry both fuel and the oxygen needed to burn it—an expensive proposition. A future craft with both scramjet and rocket power could travel to the edge of space before firing its rockets, requiring less oxygen and leaving more room for the payload.

To test that theory, NASA contractors built three X-43As; the first was to have flown last June, becoming the first air-breathing craft to fly at hypersonic speeds. But the mission ended in disaster even before the scramjet could fire up. The craft's Pegasus booster rocket—built by Dulles, VA-based Orbital Sciences to carry the X-43A to 29,000 meters and Mach 7 before its scramjets ignited—went violently out of control just seconds after the two mated vehicles were released from their B-52 carrier plane, forcing mission controllers to send an auto-destruct signal.

Late last year a NASA investigative board tentatively blamed the disaster on the Pegasus rocket, ruling out the X-43A as the cause of the failure. Charles R. McClinton, technology manager for the scramjet program at the NASA Langley Research Center in Hampton, VA, says, "We're convinced that we can be back to flying by the end of this year." If the agency does get its craft off the ground, those waiting for a cheaper, more efficient way into space can begin to breathe easier. *—Wade Roush*

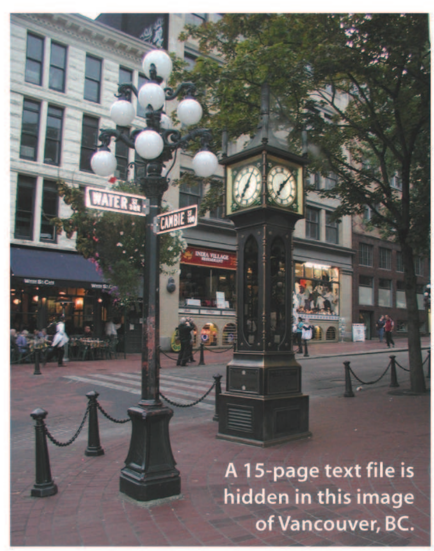
HIDING IN PLAIN SIGHT

SOFTWARE | **In the weeks after the September 11 terror attacks, reports surfaced that terrorists might have communicated with each other through messages embedded in images posted on the Web. So far, no such hidden communications have been confirmed publicly, but intelligence agencies are certainly keen on finding them if they exist. To aid in the search, a computer scientist at the State University of New York at Binghamton has developed a way to screen digital images for evidence of hidden content.**

Binghamton's Jessica Fridrich says her algorithms examine the numbers that encode color in pixels, the colored or gray dots that make up an image. When an image conceals information—say, a 15-page text file—the numbers that encode its pixel colors are changed slightly. While the human eye can't see the resulting color changes, Fridrich's algorithms can detect statistical anomalies in the underlying numbers. In most kinds of image files, Fridrich's tool can detect the signatures of a number of concealment—or "steganography"—programs, all widely shared in the hacker subculture. Cryptographers must then decode any images that have been altered.

Fridrich delivered the first version of the software to her U.S. Air Force sponsors last year. "What they do with it, I'm not allowed to know. We can only assume the government is somehow using it," she says.

"Her work is first rate," says computer scientist Rafael Alonso, technical director of Web informatics at Princeton, NJ-based Sarnoff. But the software requires investigators to make preliminary guesses about which Web sites might harbor images with hidden messages. In the future, says Alonso, to narrow the range of images to scan, algorithms like Fridrich's might be combined with search engine software capable of "shining a flashlight in the sewers of the Web"—dredging obscure sites like personal pages and classified ads that are presumably attractive for covert communications.



A 15-page text file is hidden in this image of Vancouver, BC.

Fridrich predicts "sharp competition in the next few years" from other approaches to ferreting out hidden messages. Security won't come easy, though. Information could be stashed in video and music files as well as photos, for example. Still, Fridrich's tools mark an important first step toward finding pictures that contain thousands of words. *—David Talbot*

COURTESY OF JESSICA FRIDRICH (HIDING IN PLAIN SIGHT); COURTESY OF NASA (SCRAMJET)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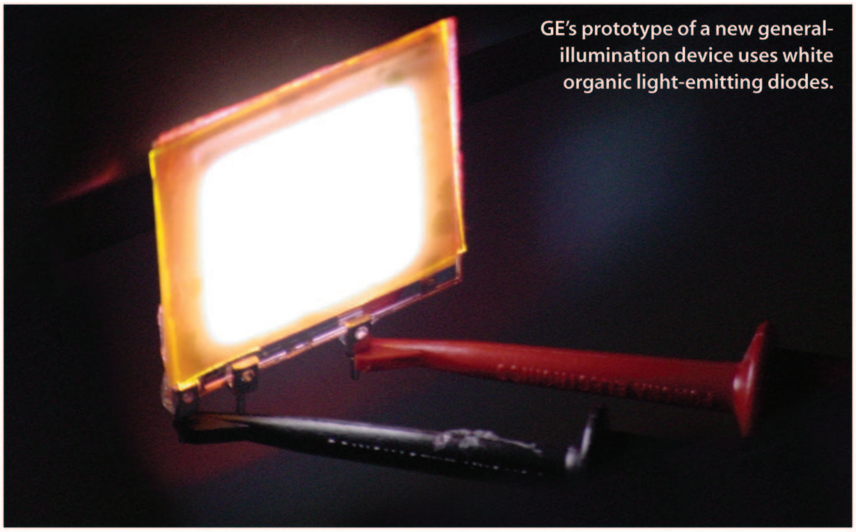


GE's prototype of a new general-illumination device uses white organic light-emitting diodes.

A NEW LIGHT

Glowing plastic could mean a dim future for the light bulb

MATERIALS | Wired to a small battery, the two-and-a-half-centimeter patch of plastic at General Electric's research center in Niskayuna, NY, gives off a soft white light. A version of this material could one day form large glowing sheets with the same long life as fluorescent lights but requiring less electricity. Indeed, this patch could represent the future of indoor lighting.

"You are not talking about a light bulb," says chemist Anil Duggal, manager of GE's light energy conversion program. "This stuff will be like wallpaper." The material is made up of organic light-emitting diodes—layers of organic materials that could be fabricated in sheets that are both thin and flexible. Apply electricity and the sheet produces a soft, steady glow. Other companies use organic light-emitting diodes in thin computer displays *(see "A Bright Future for Displays,"* TR *April 2001)*, but making a material appropriate for lighting homes required the development of diodes that emitted white light. Last fall, Duggal accomplished that by overlaying a bluish-colored diode with a phosphor that transformed the blue light into white.

Philips Lighting, Osram Sylvania and others are also developing white organic light-emitting diodes. But GE seems to lead the pack, says Jim Brodrick, program manager for efficient lighting technologies at the U.S. Department of Energy: "The GE prototype is the most efficient that we are aware of." While the material now uses 25 times more power for its light output than fluorescent bulbs, Duggal says organic light-emitting diodes' efficiency could ultimately surpass that of fluorescent lighting.

The lighting sheets could also have advantages over their technological cousins, light-emitting diodes (LEDs). Made of inorganic materials, LEDs flash in stoplights and car headlights. Some companies are investigating their use in general-purpose lighting, but the soft light of organic light-emitting diodes is better suited to a living room than the glaring beams of LEDs, says Brodrick. More important, the organic technology is amenable to mass manufacture through a printing technique, which is potentially far cheaper than the chip fabrication methods required for LEDs.

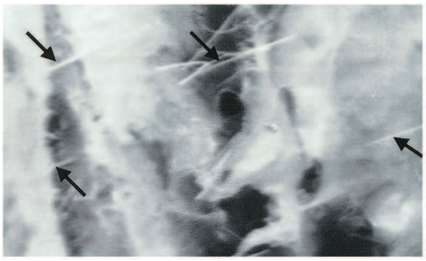
It could take a decade before GE's glowing material reaches the interior-lighting market, though products like flexible signs or billboards could come sooner. "The lighting industry as a whole—the market, the customers—is extremely lethargic in terms of new-technology adoption," says Bill Ryan, group product manager for LEDs at Philips Lighting in Somerset, NJ. "But this area clearly has the potential for being a disruptive technology." If it reaches its potential, it could eventually mean lights out for century-old incandescent technology. —*David Talbot*

SKELETON RECHARGE

BIOTECH | It's not quite Mary Shelley's image of a corpse brought to life by electricity, but biomedical engineers have found a way of using electricity to bring artificial bone to life. The method could one day yield bone replacement parts.

Bioengineer Rena Bizios at Rensselaer Polytechnic Institute uses carbon nanotubes—tubular molecules that are good electrical conductors—to deliver electricity to bone-forming rat cells deposited on a piece of polymer. Researchers have long known that electrical stimulation enhances bone growth, but it's hard to deliver the electricity uniformly: new bone tends to clump around the electrodes delivering the charge. Bizios's technique could solve that problem, though, since the nanotubes are embedded throughout the polymer. When the researchers turned on the electricity, the bone cells grew and began to deposit the proteins and calcium that give bone its strength. That the technique worked so well "was a great surprise," says Bizios.

Researchers don't know yet if the approach will ultimately yield uniform bone tissue, but the results are "very exciting and very promising," says Antonios Mikos, a biomedical engineer at Rice University. While doctors can treat small bone injuries by surgically implanting patchlike materials, they can't yet generate the large sections of bone that would be needed to replace a hip ravaged by osteoporosis, for example. Bizios's material, on the other hand, opens up the possibility of quickly growing large sections of artificial bone in the lab using a patient's own cells and nanotube-wired polymer scaffolding. Surgeons could then replace any damaged or diseased parts of a patient's skeleton with the new bone. —*Alexandra Stikeman*



Arrows indicate nanotubes in Rena Bizios's bone-growing material.

VIDEO OBJECTIFICATION

New tools have computers seeing things

INTERNET | When a computer processes a visual image, it's like a museumgoer standing too close to a pointillist painting: all it sees are rows of colored dots. But the next step forward for video processing could, in effect, be a step back; new digital technologies are beginning to discriminate objects.

Object discrimination presents the possibility of "saving a lot of bandwidth," says Eran Yarom, CEO of Tel Aviv, Israel-based startup EnQuad Technologies. EnQuad has developed an algorithm that analyzes digital video streams and "extracts the object from the background in real time," says Yarom. "Then we're able to send the background and the moving object separately." Video from the Winter Olympics, for instance, might feature a skater, an ice rink and an audience. The position of the skater needs to change with every frame of video; but transmit the rink and the spectators at a lower resolution, with less frequent updates, and you can cut your bandwidth requirements by three-quarters. EnQuad's first product will be a digital signal processor that performs such selective transmission; Yarom expects it to reach the market by mid-2002.

Another Israeli startup is taking a hardware approach. A video camera from 3DV Systems of Yokneam, Israel, uses an infrared laser to gauge depth; existing graphics software can use that depth information to extract objects from the video stream. The startup's vice president, Arend Verweij, says that the camera could be used, for example, for high-resolution videoconferencing.

Object extraction techniques can also help determine what's going on in a moving image. John Clark, vice president of product management at ObjectVideo in Reston, VA, thinks the technology's best short-term prospect is in video surveillance. "Surveillance cameras are everywhere," Clark says, "recording a whole lot of valuable information, and in the vast majority of cases there's nobody there to watch it." ObjectVideo's software could alert building security guards if a visitor entered a restricted area, for example—or left behind a bomb-sized briefcase on the way out. The company hopes to have a commercial product available by the end of the year.

Industry experts predict that these and similar techniques will ultimately carve up all video on the Web—at which point Britney Spears will *really* be the most objectified girl on earth. —*Larry Hardesty*

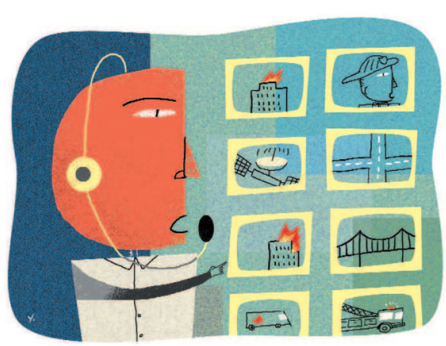
3DV's camera can isolate objects in a video stream.

DATA TO THE RESCUE

SOFTWARE | **When there's a major catastrophe, whether it's a terrorist attack or an earthquake, reliable information can be as vital as blood supplies. To aid emergency workers, a team from the State University of New York at Buffalo is developing software tools that should make getting that information—and making sense out of it—much easier.**

"If you begin to look at current crisis management infrastructures, they're messy. It's helter-skelter," says James Llinas, director of the university's Center for Multisource Information Fusion. The group is in the first year of a five-year project to make software systems that collect and interpret bits of disparate data—news broadcasts, 911 calls, satellite imagery, reports from fire and police departments, even readings from remote sensors attached to roadways and buildings—in a process known as information fusion. Currently, an official trying to ascertain road damage in the aftermath of an earthquake might have to keep one eye on the TV news while listening to both radio traffic reports and the police scanner. Since most of these data are available in digital form, the software could take them all in, process them and present a report outlining the best evacuation routes.

The center is using the 1994 Northridge, CA, earthquake as its first case study, but the software could be used for a variety of scenarios and tailored to any organization from the Federal Emergency Management Agency to a local fire department. At present, few of the agencies that respond to disasters use any decision support software. And, says Llinas, the center's effort marks the first significant attempt to apply information fusion—long used by the U.S. military to streamline intelligence and surveillance operations—in civilian settings.



Steve Charvat, disaster recovery manager for the Washington, DC, Emergency Management Agency, is hopeful yet cautious about the new system. "The end product sounds great," he says, "but until I actually see something better, the human brain still makes the best filter in the heat of battle." But when the Buffalo programs become operational in a couple of years, Charvat and other emergency responders might just get some help in making the tough decisions. —*Kevin Hogan*

JAMES YANG (ILLUSTRATION); COURTESY OF 3DV SYSTEMS (VIDEO)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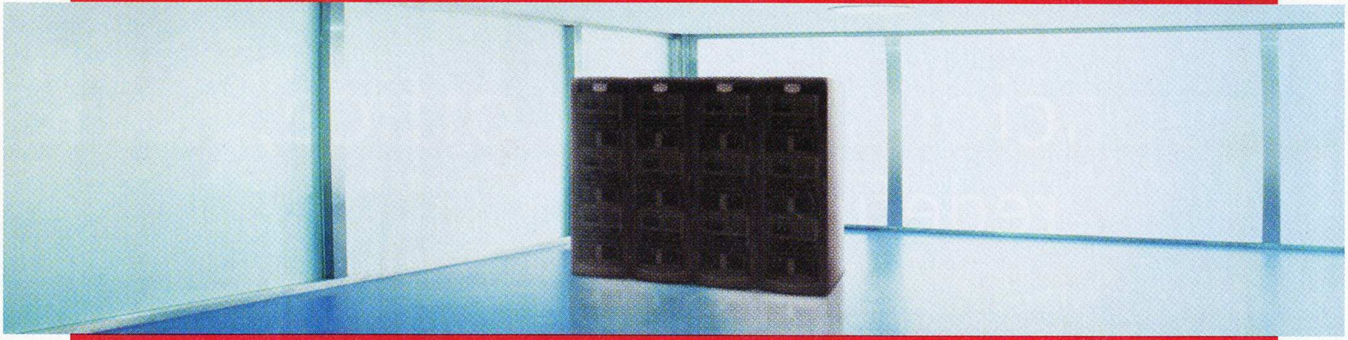
MANUFACTURING: AUTOMATED IN 1913



THE CORPORATE DATA CENTER: AUTOMATED IN 2002

THE COMPAQ ADAPTIVE INFRASTRUCTURE IS ABOUT TO CHANGE EVERYTHING.

Technology has automated just about everything these days. But curiously, the corporate data center has lagged behind. There, highly skilled people still spend inordinate amounts of time doing things like manual fault searches and mindlessly repetitive server management tasks. It's more than ironic. It's enormously counterproductive. Because every initiative a corporation undertakes—whether it's in operations, marketing, accounting or HR—goes through the data center.

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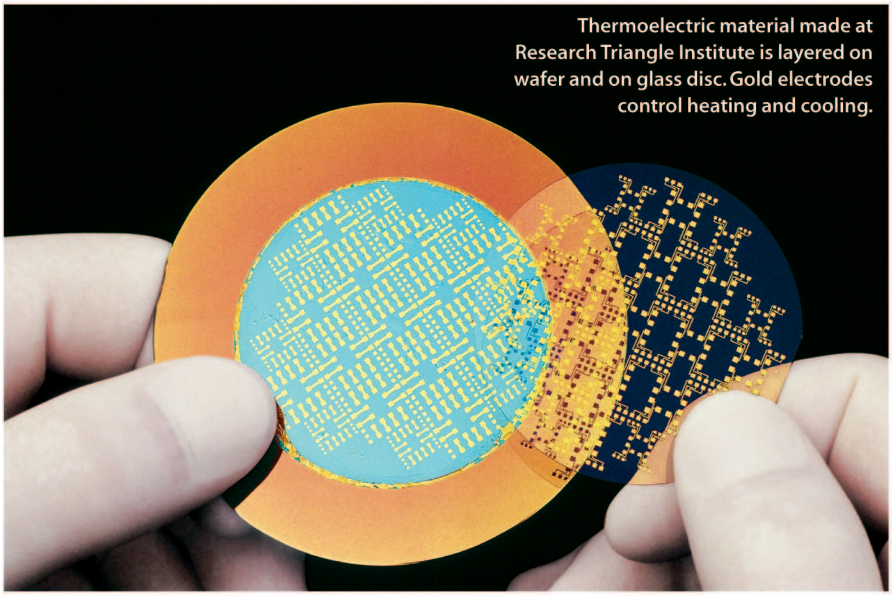


Thermoelectric material made at Research Triangle Institute is layered on wafer and on glass disc. Gold electrodes control heating and cooling.

JOHN THEILGARD, RTI INTERNATIONAL

THERMOELECTRIC MATERIALS

Electricity from waste heat is just one of the potential uses

The promise of thermoelectric materials has, it seems, run hot and cold over the decades. These materials, which can directly convert heat into electricity (and vice versa), could be a boon for everything from power generation to microprocessor cooling. But except in a few niche applications, these solid-state heat pumps have proven too inefficient to be practical. As much as engineers would like to grab waste heat from, say, a car's engine and turn it into electricity, thermoelectric materials just haven't been up to the job.

Now, engineers and scientists at several leading labs have used nanotechnology to create novel semiconducting materials that could finally make thermoelectricity a widely used technology. "After six to 10 years of pretty intensive basic research, some of these materials are coming to fruition," says Terry Tritt, a professor of physics at Clemson University. "Within the last 18 months there have been substantial improvements." Indeed, at least one research group predicts it will soon have prototypes of a practical heat-conversion device that carmakers can begin testing.

In its simplest form, thermoelectricity is produced when you heat one end of a wire; electrons will move to the colder end, carrying electrical charge with them and producing a current. Alternatively, you can apply a current to the wire to carry heat away from a hot section to cooler areas. Since the 1960s, NASA has used this effect to generate electricity for spacecraft too far away from the sun for solar cells to operate. And one Japanese company is even selling thermoelectric wristwatches powered by the wearer's body heat. But the materials have so far been used only in novelty items because of a catch-22: to make the process efficient, you need materials that will conduct electricity, but that do not excel at conducting heat, so the temperature difference remains. In other words, the trick is to somehow block the heat flow while enhancing the electrical flow.

That's where nanotechnology comes in. "Nature is working against us with these materials," explains MIT physicist Mildred Dresselhaus. So, she says, starting in the mid-1990s, her group and several others turned to nanoscale structures to improve on nature at the molecular level.

Last October, Rama Venkatasubramanian at the Research Triangle Institute in North Carolina reported a major advance: tiny "superlattice" structures that appear to be more than twice as efficient as previous thermoelectric materials. The nano films consist of several alternating layers, each less than five nanometers thick. These layers block the travel of atomic vibrations that produce heat flow but still let the electrons flow as current.

The material's first application could be a device for siphoning off electrical power from the heat in automobile exhaust. Eventually such a device could be used to supplement power from electric and fuel cell engines or provide a conventional vehicle with most of its electricity needs, running everything from its radio to its air conditioner. Venkatasubramanian also envisions the material's use in microelectronics. The heat buildup in today's ultrafast microchips is, in particular, a problem in making smaller and faster devices. Tiny patches of the films precisely positioned on microelectronic chips could be used to spot-cool only the components that need it.

Other research groups are making nanowires and nanodots for thermoelectric applications. At the University of California, Berkeley, for example, chemist Peidong Yang has found a way to grow 20-nanometer-wide wires made of a combination of silicon and germanium for use in nano heating and cooling. And at MIT's Lincoln Laboratory, a group led by Ted Harmon has synthesized arrays of tiny nano particles. The arrays contain thousands of so-called quantum dots—each only a few nanometers in diameter—and are capable of acting as microcoolers or power generators.

Indeed, many researchers feel they are finally within striking distance of an efficient way to directly extract electricity from heat sources. Thermoelectric materials will first appear in specialty applications, but if efficiencies can be cranked up further, then whole other areas of technology will be fair game, from refrigerators to turbine power generators. —*David Voss*

IDENTITY CARD DELUSIONS

More than 200 million Americans carry driver's licenses with them every day. The small plastic cards denote the holders' right to operate a motor vehicle. But that rather understates things. Today, all manner of business establishments, from banks to airlines to bars, will deny you service if you do not show them your driver's license. In other words, driver's licenses have become the de facto identity cards of the United States.

Now the American Association of Motor Vehicle Administrators, a kind of trade organization for the state motor vehicle registries, wants to make things official. This past January the association asked Congress for $100 million to link all of the state motor vehicle databases into a single national system, overhaul licensing procedures and phase in a new generation of high-tech cards. If this proposal goes through, driver's licenses issued in two years will almost certainly be high-tech, biometric-endowed cards for the absolute identification of the cardholder.

And this is just the beginning.

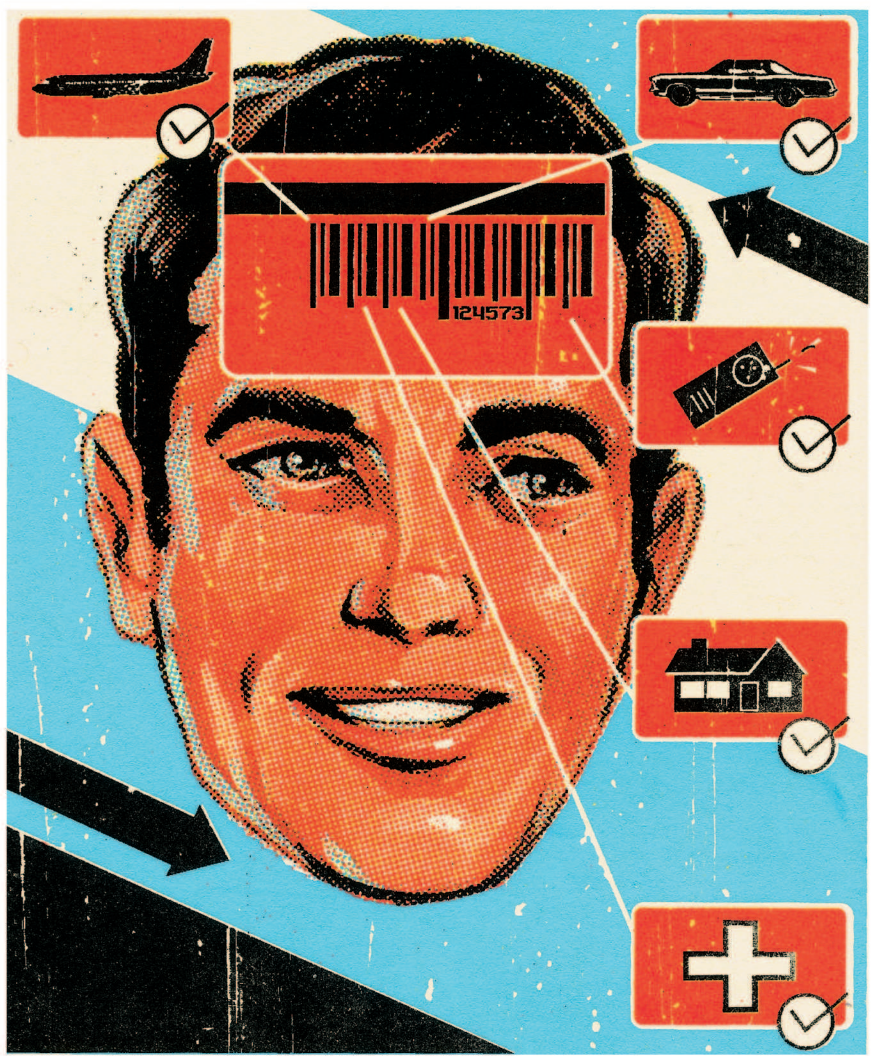
Less than two weeks after the motor vehicle announcement, the U.S. Department of Transportation announced that it was moving full speed ahead with plans to create a nationwide "trusted-traveler" card—another biometrics-based national identification card. But instead of granting permission to drive, the proposed trusted-traveler card will allow the holder to breeze through security checkpoints at airports without being detained by lengthy interviews and intrusive searches.

It has long since been a cliché to say that September 11 changed everything, but one thing that has certainly changed since that fateful day is America's receptivity to the idea of a national identity card. Eight months ago, such cards would have been unthinkable, the first step toward an Orwellian surveillance society. But priorities have shifted. Many of those who once steadfastly opposed the ID card now see it as an unfortunate but necessary measure to protect "homeland security."

America is being sold an empty promise. The proposals for new biometrics-based identity cards will certainly let the states buy shiny new computer systems and deploy ominous Big Brother-style networks, and the cards will speed the passage of frequent travelers through the airports, but they won't significantly improve the security of Americans. Indeed, had these systems been in place on September 11, they would not have prevented al-Qaeda's deadly hijackings.

The push to turn the driver's license into a national identity card is coming not from the federal government but from the states. Motor vehicle administrators and police alike want to stamp out the scourge of fake out-of-state driver's licenses—what many college students call their "drinking cards." But replacing today's patchwork of different-looking driver's licenses with a single nationwide standard that's all but impossible to forge will also confer many advantages for law enforcement agencies, because bogus out-of-state driver's licenses are used by crooks engaged in identity fraud, people who keep driving despite their suspended in-state driver's licenses and other assorted hoodlums.

The states are also eagerly looking at biometrics as a powerful tool for verifying identity, preventing fraud and enlisting the driver's-license database to help solve other crimes. States that digitize driver's-license photographs can



TAVIS COBURN

use face recognition systems to find out if the same person has multiple identity cards issued in different names. (Last year the Mexican Federal Election Institute adopted this technology to help stamp out duplicate voter registrations.) Likewise, states that collect fingerprints when issuing driver's licenses can store that data in their automatic identification systems and then match it against fingerprints found at crime scenes. Many U.S. murder cases from the 1970s and 1980s that had gone cold were solved when fingerprints were brought online in the early 1990s.

But moving this biometric information out of the states' databases and onto the back of the individual's driver's license—one likely result of the September 11 attacks—would be a mistake.

Technically, it is simple enough to do. A two-dimensional bar code, for example, can easily hold digitized representations of a person's photograph, fingerprint or handwritten signature. And two years ago, the motor vehicle registries' organization adopted a nationwide standard for encoding such information. Putting the information on the back of the driver's license allows any business to use your biometrics to verify your identity. It also makes it that much easier for businesses to scan the information and add it to their files. Ironically, users of these new driver's licenses would be *more*, not less, susceptible to identity theft, because so much more of their personal information would be in circulation.

Instead of bar codes, our next-generation identity cards might contain computer chips. A typical chip card, or "smart card," can hold more than a page of typed information. Some smart cards have encryption keys and tiny cryptographic processors, allowing them to engage in secure e-commerce-style transactions. In theory, a chip could allow multilevel access to the personal information that the card contains: a tavern, for instance, would be allowed to read your age, but not your name or address. Airlines would presumably be given access to the whole shebang, allowing them to use fingerprints or retina scans to biometrically verify the identity of every passenger boarding their flights.

But despite their high-tech appeal, smart cards have a checkered track record when it comes to protecting the information they store. In Europe, where smart cards are widespread, hacking them to get free telephone calls or free satellite television is a cottage industry. If some U.S. businesses have access to the "secure" area of smart cards, I find it hard to believe that the relevant know-how and codes won't, over time, migrate to criminal elements. Already, there are many cases of crooked clerks giving credit cards a second swipe at department stores and making their own copies of their customers' credit card numbers. If some crook steals your fingerprint, you're going to be vulnerable to a lot more than simple credit card fraud.

What's worse, the harder one of these new identification cards is to forge, the more valuable a forgery will become. It only takes one corrupt official to create a steady stream of fake, unforgeable IDs for the bad guys. And don't forget, the government will need its own supply of fake IDs for undercover cops, spies, informants and the like.

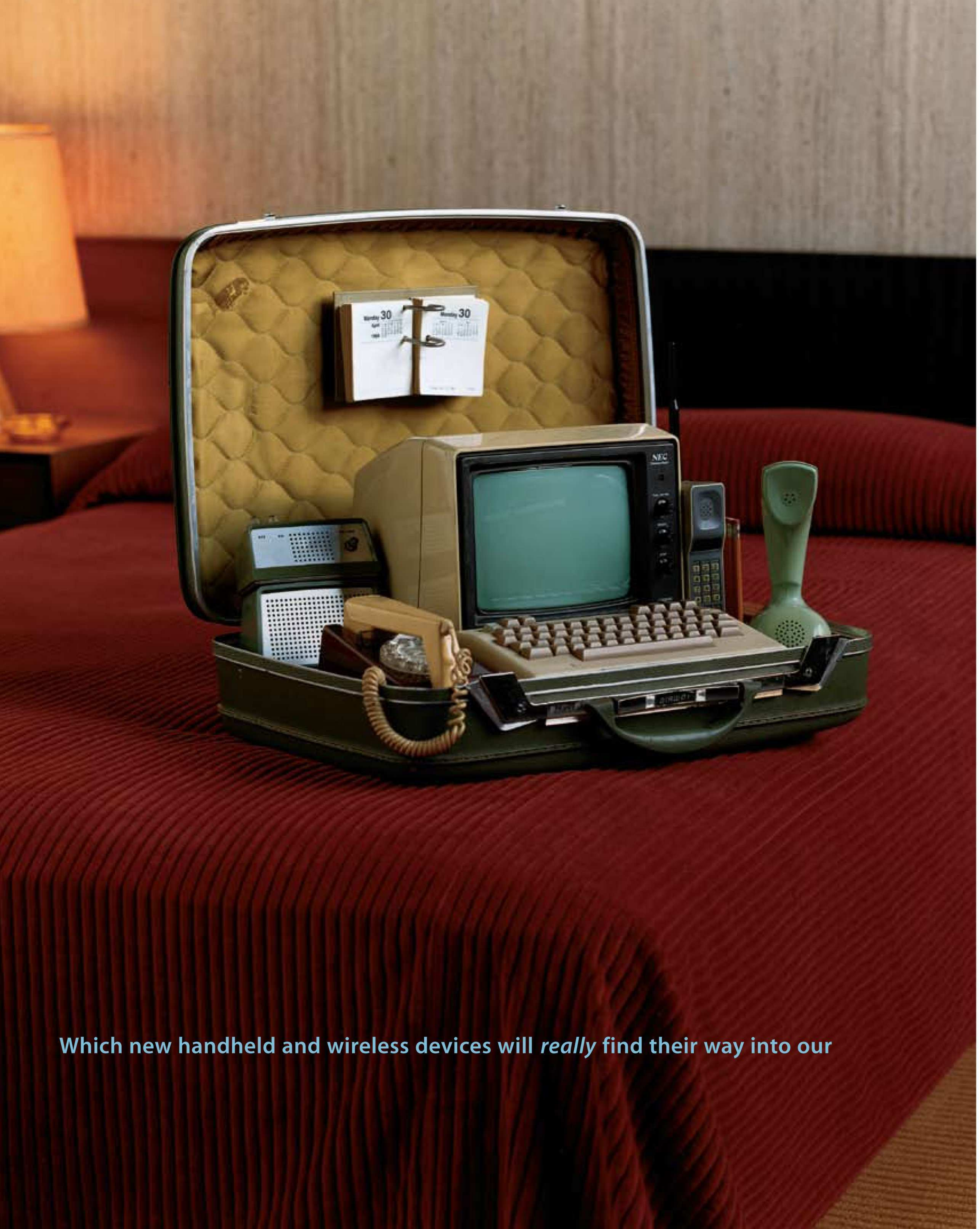
But what's most disturbing about these new identification systems and policies is that they won't accomplish their stated purpose—they won't make Americans more secure against terrorists. As our leaders have told us time and again, the current war requires fortification of our homeland security to defend against a foreign threat. But foreigners traveling inside the United States are not required to get U.S. driver's licenses—not even if they want to rent a car. Hertz, Avis and National Car Rental, for instance, will happily rent to any driver who has a valid license from Egypt, Israel or Saudi Arabia.

America is being sold an empty promise. Proposed new biometrics-based driver's licenses will let the states deploy ominous Big Brother-style networks but will do little to protect us from terrorists.

If our officials are worried about more al-Qaeda "sleeper cells," then they will be looking for people who have no former record—people who might even stand up to an FBI background check. Recording the fingerprints of an Egyptian businessman on the back of a Florida driver's license won't tell us if that person has a vial of smallpox in his shaving kit. And if some Saudi student with 100,000 kilometers in his frequent-flyer account and information about crop dusting on his laptop computer asks for a "trusted-traveler" card, he'll probably get one.

Like the FBI, which tucked a laundry list of new powers into the USA Patriot Act of 2001, the American Association of Motor Vehicle Administrators and the Department of Transportation are using the terrorist attacks as a convenient excuse for deploying a national identification system that would have been politically untenable this time last year. Remember, even if the September 11 terrorists had been carrying smart-card-enabled driver's licenses with biometric authenticators, they still would have been allowed to board their flights. American Airlines knew Richard Reid's identity—it just didn't know that he had plastic explosives concealed in his shoes.

Forcing every American to carry a new state-issued identification card may cut down on illicit drinking and make things easier for police at traffic stops, but it is simply not a rational way to deal with the specter of terrorism. Better identification systems won't do much to stop people who have evil in their hearts but not in their history. TR



HAND-HELDS of TOMORROW

Which new handheld and wireless devices will *really* find their way into our pockets? Human-factors engineers are interested in practical answers to that question, not fanciful ones. No wonder no one listens to them. By Claire Tristram

Photograph by Eric Tucker

KEN PUGH IS THE FUTURE.

Mr. Pugh is drinking coffee in a Starbucks in San Jose, CA. He has many gizmos hanging from his belt. A cell phone, complete with stars-and-stripes face plate. A headset for his phone. A pager. A separate wireless device with a tiny screen and thumb-sized keyboard for tapping out e-mail messages. A digital organizer. "You could call me a gearhead," he says, with pride. "My only complaint is that I have to carry so many things." His phone beeps. He answers it, with a bit of a flourish, as if to demonstrate his gearheadedness.

It's a generally accepted belief—in the computer industry, at least—that it's only a matter of time before everyone will want to be just as connected as Mr. Pugh, whom I meet while pondering our digital future over a grande mocha. In Japan gearheads are typically teenagers, known as the *oyayubizoku*—literally, "clan of the thumbs"—for their enthusiasm for tapping out messages to one another with their thumbs on their cell phones. Here in Silicon Valley it's usually the business travelers, like Mr. Pugh, who are the ascendant gearheads. Electronics giants and startup ventures alike are trying to get those of us not in either category just as hooked on handheld digital devices.

But what gizmos will we really carry? Unlike the personal computer, which has had its basic design more or less set in stone for the last 20 years, gizmos are a wide-open field, where it's not at all clear which digital things, if any, people will want to bring along in their pockets and purses. The cell phone has made strong inroads, of course—52 percent of households in the 25 largest urban markets surveyed in the United States now have at least one, according to a September 2001 J. D. Power and Associates study, and in some European countries such as Iceland and Finland the figure exceeds 75 percent. Other digital devices have made progress as well: worldwide sales of digital organizers reached an estimated 12 million units last year. Consumers bought an estimated 6.4 million digital cameras in 2001, and they're expected to scoop up at least three million MP3 players this year. All of these are, or promise to be, multibillion-dollar businesses.

Encouraged by such statistics, some companies are offering next-generation devices that give consumers either new ways to do old things or new functions we didn't know we needed. At last November's Comdex, the world's biggest trade show for consumer electronics, Bill Gates spent much of his keynote speech predicting the coming popularity of tablet-style wireless computers, which will supposedly replace today's keyboards with pen-based computing. National Semiconductor was pushing for its all-in-one Geode Origami Mobile Communicator, a prototype that folds up into different shapes depending on its use, transforming itself into a digital camera, a digital video recorder, a videoconferencing terminal, an Internet access device, an Internet picture frame, an MP3 player and a few other things to boot. A company called Senseboard Technologies showed off its virtual keyboard, which lets you type in the air by measuring the movements of your fingers and converting them to readable e-mail messages. Then there was the Chat Pen from Ericsson, which records your handwriting on digital paper, transmits this digitized scrawl to your cell phone, and sends it along to any e-mail address. There are countless others, in prototype and production.

Most of these concepts, of course, will tank. Not because they don't offer enough processing power or storage capacity. Not because they don't offer compatibility with the latest wireless protocol. Not because they don't do what they're supposed to do, although that can be an issue. Unh-uh. The ultimate success or failure of any given gizmo will depend on a million or so people picking it up and deciding whether it feels good or not.

"Most good products are designed around the person, not the technology," says Donald A. Norman, principal at Fremont, CA-based Nielsen Norman Group and author of *The Invisible Computer*, a manifesto for replacing "technology-centered" products with "human-centered" ones. "It's not a case of people saying, 'Gee, look at this neat technology.' It's a case of people saying, 'Gee, look at what this thing can do for *me*.'"

And therein lies the problem. For many years the art of human-factors engineering has been neglected by the computer industry. But as computing power seeps from the desktop further into our daily lives, it's becoming all the more important to make products that are both easy to use and improvements on what we're using today. A human-factors approach assumes that the things we'll carry in the future are not going to be invented so much as *discovered*—that the answer to the question of what devices we'll carry will become obvious as we learn more about human behavior.

Step 1—Field Research

Jakob Nielsen is annoyed.

Norman's partner in the Nielsen Norman Group has just finished giving a conference on user interface design. But what Nielsen believes to be the most important presentation—how to conduct field studies on human behavior—was presented to rows of empty seats. "Most people think of design as a debugging process," he grumbles. "They think you come up with a product, then go ask people what's wrong with it. To my way of thinking that's exactly wrong. The best products are going to come out of following people around."

Years of following people around has given Nielsen definite opinions about what people want. They want consistency, for example. To know that a given action will cause a predictable reaction—like ringing a doorbell or dialing a telephone number.

"That's why pen-based computing has never taken off, and never will," he says with a dismissive wave. "You have to check it all the time to see if it's working. It's also difficult to correct mistakes. It's the same with voice recognition. It will take 20 years before voice recognition technology is reliable enough for people to want it."

UNLIKE THE PERSONAL COMPUTER, WHICH HAS HAD 20 YEARS, GIZMOS ARE A WIDE-OPEN FIELD, WHERE IF ANY—PEOPLE WILL WANT TO CARRY ALONG IN

So what *do* people want? Andrew Odlyzko, a former AT&T Labs researcher who now directs the University of Minnesota's Digital Technology Center, believes from his own studies of human interaction with digital things that people will always look to their wireless gizmos mainly for communication, not

21st-century rolltop: Ideo built this concept laptop, with its pull-out screen and keyboard, to be both portable and drop-proof.

RICK ENGLISH/IDEO

entertainment. "If we look at what most people will want [from wireless devices], it's interaction with other people," Odlyzko says. "That's why cell phones are such a success."

Nielsen, too, is upbeat about the usefulness of an integrated communications device—if designed correctly: something that would include voice and e-mail and instant messaging, combining all of Mr. Pugh's gizmos into one neat package. Such a

ITS BASIC DESIGN SET IN STONE FOR THE LAST
IT'S NOT AT ALL CLEAR WHICH DIGITAL THINGS—
THEIR POCKETS AND PURSES.

device would have as large a display as possible and eschew voice commands and pen-based computing for a simple qwerty keyboard. It would also include Global Positioning System capability, in order to give you what you need where and when you need it. "Say I need a taxi," says Nielsen. "I pull out this device and can see where cabs are available and how long it will take them to get to my position. I call one by touching the screen. I don't have to call five companies. I don't have to tell them where I am. I don't even have to stay where I am. The cab finds me."

But Nielsen doubts that people will use these integrated devices to surf the Web when they're away from home—another beloved concept among gizmo developers. "The average person will *not*," he asserts. "The wireless connection will always be more expensive. The device will always be more cumbersome than what you have at home. And you're not going to be in a nice office in front of a big color monitor—you're going to be standing in the rain at a bus stop, paying by the packet."

What will happen instead, Nielsen and Odlyzko predict, is that people will carry their entertainment in a specialized, nonwireless device, taking advantage of ever cheaper storage and ever more powerful processors. Yesterday's Sony Walkman and today's tiny MP3 players are harbingers of this trend. "The argument for getting content over the air is rather weak," says Odlyzko. "It's more likely that people will download informa-

tion into their own, recordable device that they will carry with them and play when convenient."

I come away from these conversations envisioning a future where we carry two primary gizmos, each used for very different reasons. (Add any additional gizmos, and we run into what Odlyzko warns will be a quagmire of competing devices that serve no useful function other than losing investors' money.) The first gizmo, the one designers are focusing most of their attention on today, is our preferred communications device, the one that keeps us in touch. The second is our content-rich device, which allows us to carry our entertainment and even our computing power along with us. Neither function is particularly well served by existing products: cell phone and personal digital assistant screens are too ridiculously small, and laptops are too bulky and fragile. In other words, there is plenty of room for improvement based on human-factors principles. "The key is to remember that people don't want to fool with it," Nielsen says. "They just want it to work. It's a matter of getting things to work the way people think."

Step 2—Concept

Dennis Boyle is a gizmo maniac.

Boyle brings *eleven* digital organizers to our meeting—all devices he has used himself over the years, beginning with the Apple Newton and ending with the Handspring Visor, a digital organizer complete with a camera add-on that Boyle helped to design himself. He gleefully takes my picture with it, entering my likeness into his digital contact list. "It's handy," he says, a bit defensively. "Now I can look you up, see the picture, remember who you are." He and Rickson Sun, who also takes part in our interview, are 20-year veterans at Ideo, the award-winning design organization in Palo Alto, CA. Talking about the future of gizmos gets them energized.

Sun leaps up from his chair and begins to write words on the whiteboard in one of Ideo's conference rooms: *coins, watch, pen, keys, phone, wallet.* Under *wallet* he writes *currency, receipts, photos, credit cards.*

"Okay, what do we carry today?" he says. "Things that identify us. Things that give us access. Things that let us communicate." He begins to draw circles grouping some of the words together. "You can already see how some of these things can be combined or replaced." The things Sun groups together are logically related: a wallet, for example, could be replaced by a digital organizer, with credit cards and receipts and photos stored digitally on the same device. "Keys could go away with biometrics," Sun adds, referring to technology that can verify an individual's identity using physical characteristics such as fingerprints. Coins could be replaced by an electronic barter system that automatically keeps track of your funds and offers on-the-spot discounts. Compared with Sun's groupings, combinations such as phones with FM radios (a concept currently being touted by Nokia) seem downright silly.

On the communications side, Sun assumes that some number of people will inevitably want to fold voice and data communications into a handy package. "Voice and e-mail and instant messaging all serve related needs," he says. "Giving people access to all of them while still allowing them to get up and walk around is very empowering."

Right now, though, it's hard to find all of these functions in one package. The BlackBerry two-way pager from Waterloo,

Holy trinity: Handspring's new Treo packs voice communications, e-mail and instant messaging into a personal digital assistant.

PHOTOGRAPH BY ANNE HAMERSKY

Ontario-based Research in Motion, for example, offers e-mail and instant-messaging services but no voice communications. Cell phones carry voice signals but very limited data. A gaggle of handheld designers are now racing to provide a convenient way to integrate all three functions.

Whatever the designers come up with, Boyle and Sun (like Nielsen) bring up almost immediately how important it is to give people a consistent, predictable outcome—some reaction to an action that will happen every time, without question. Yet from the advent in 1989 of GRiDPad, the first pen-based tablet computer, to Bill Gates's keynote speech at Comdex last November, there has been a collective conviction among computer companies that handwriting recognition will replace the keyboard. Ideo itself worked on the GRiDPad and many other pen-based devices that were beautifully designed yet utterly inappropriate for sending e-mail messages. Then came the BlackBerry—no bulkier than a remote control for a garage door opener, yet equipped with a curved qwerty keyboard that allows thumb typing at up to 30 words per minute. "No one had ever gotten around how to make the keyboard small enough," says Boyle, "until someone figured out, okay, if you're going to be all thumbs with these things, then so be it." The BlackBerry's easy-to-use interface has helped make it into a cult item among gearheads—and the new standard for wireless e-mail and paging.

While Ideo missed the thumb keyboard, it does have a record of ferreting out solutions that resolve equally contradictory goals. Take, for instance, Ideo's concept design for a future laptop computer. As engineers have learned how to squeeze more computing power and longer-lasting batteries into smaller and smaller spaces, Sun and Rickson observe, designers have been able to make laptops lighter and more portable. But this added convenience has often come at the cost of durability, which is why anyone who drops a state-of-the-art laptop on airport linoleum may discover that it's damaged beyond repair. Ideo's futuristic concept of the laptop, by contrast, will be both more portable *and* more durable: a metal tube from which screen and keyboard roll out like window shades.

What other considerations does Ideo take into account when designing a handheld product? One big one is that people value their acquired skills, no matter how ergonomically dysfunctional. This means they want their phones to look like phones. "Whether it's a good thing or not, some people are used to holding phones with their neck and walking around changing diapers or typing," says Sun. "It's a highly evolved skill. You don't want to take those kinds of things away from people."

Again, disingenuously straightforward observations. Make things that always do what people expect them to. Build them to make these things easier rather than more complicated. Make them look and feel familiar.

Three simple ideas, but they rule out so much of what is envisioned for our digital future. Like that typing-in-thin-air keyboard. Gone as well are pen-based tablets, no matter how much Bill Gates tells me I want one. I flash on an image of myself at next year's Comdex, walking past rows of now empty booths, each company's innovations done in by their inability to provide an answer to one fundamental question: "What do people want?"

MAKE THINGS THAT DO WHAT PEOPLE EXPECT THEM TO. BUILD THEM TO MAKE THESE THINGS EASIER RATHER THAN MORE COMPLICATED. MAKE THEM LOOK AND FEEL FAMILIAR. THREE SIMPLE IDEAS, BUT THEY RULE OUT SO MUCH OF WHAT IS ENVISIONED FOR OUR DIGITAL FUTURE.

Step 3—Product

Peter Skillman's office is a mess.

To begin with, there are the trays full of competitors' products, eviscerated. "We take 'em apart in our team meetings," he says. "Incredible how different they are. This was a Nokia 8290. Very few parts. It's designed for rapid assembly. Look at this one. A Sony Clié. A mind-boggling number of tiny little parts."

There are also lots of plastic jars filled with small metal bits. "Snap domes," he explains. He takes one out and tapes it to my open notebook. He notes that the torque and shape of these small pieces of metal make all the difference in how a gizmo button responds to being pressed—which in turn can mean the difference between a keyboard that works for human beings and one that doesn't. "You need that tactile feedback," Skillman says. He is famous for running around the office asking receptionists and accountants and anyone else not associated with engineering to try the touch of his latest keyboard.

Skillman is one member of a triumvirate at Mountain View, CA-based Handspring—along with Jeff Hawkins, founder of both Palm and Handspring, and Rob Haitani, Handspring's director of software and interface design—that is responsible for human-factors decisions. Skillman is the hardware guy. Until now Handspring has marketed Visor digital organizers, the first to come with an expansion slot for attachments like Boyle's camera. Now the company has entered the race to provide our primary communications gadget, creating a single device—called the Treo—that combines a phone with e-mail, instant messaging and a personal organizer.

Them and everyone else. Research in Motion, for example, proposes adding an earphone and dangling microphone to the BlackBerry. Nokia's version, the 9290 Communicator, looks like a bulky cell phone from 1995, but it opens up like an eyeglass case to reveal a handheld computer underneath, complete with a tiny qwerty keyboard. Silicon Valley startup Danger has developed the hiptop, a garage-door-opener-shaped product with a shell that's nearly all screen on top, but which pivots open to reveal a BlackBerry-style keyboard underneath. Then there's Handspring's Treo.

Skillman says his team began with a design similar to those of the BlackBerry and Danger's hiptop, with the thumb keyboard along the long side of the device. But it didn't work. He demonstrates why: "Look, you have to turn it vertically to use it as a phone, then back again horizontally to use the keyboard," he says. "It's awkward. People hate it. Our first rule was that it had to be comfortable as a phone."

Beginning with that one observation, the team threw out its original concept and settled instead on a telephone-like design that flips open vertically, with a qwerty keyboard at the bottom, along the short side, where a numbered keypad would normally be on a telephone. The keyboard lets users call people in their address books by typing the first few letters of their names. But for those who prefer to dial the old-fashioned way, some keys are also marked with numbers, as on the keypad of a conventional phone. Closed, the palm-sized Treo fits easily in one hand. It feels good, like a surf-smoothed stone you'd pick up on the beach.

IF THOSE WHO PROPOSE A HUMAN-CENTERED DESIGN APPROACH ARE CORRECT, WE'RE ABOUT TO SEE A WHOLE NEW WAVE OF PRODUCT FAILURES. BUT WE'RE ALSO ABOUT TO SEE SOME QUIET BUT LIFE-CHANGING SUCCESSES—DEVICES THAT MAKE OUR LIVES EASIER.

But how could Handspring possibly make the keyboard small enough to fit along the short end of the device? Just as Research in Motion made its breakthrough: through meticulous attention to the keyboard design. Hence all the snap domes in Skillman's office. It took a year to find a design that worked. "We really didn't think a keyboard could get this small and still be easy to use," says Skillman. "We thought people would take out their stylus and dial, and we actually had little indentations in the keys to make that easier. But it turns out people hate using the stylus. It also turns out there was a way to shrink the keyboard where it actually got *easier* to use. You can type with one thumb if you want."

He hands me the Treo and I try typing with one thumb. After only a bit of fumbling I type *this is easy*. And it is.

The resulting product puts several useful functions together in one package and makes all those things work better than they would alone. Think of something you want to do—like e-mailing a friend or scheduling an appointment—try it, and it works. "You don't have to be a rocket scientist to figure out that a fast and easy way [to connect with others] is what people want," Haitani says. "Then observing people helps to refine how this works—for example, understanding that one-handed dialing is critical, or looking at how people use [instant] messaging."

If gearhead Ken Pugh bought a Treo, he could thin his menagerie of devices down to just one. But can I hold it between my ear and my shoulder? Yes. I close it up. It isn't flashy. It won't give me full-color Web pages, or allow me to snap photos and send them to my mother instantaneously, or do any of the other things some gizmos do. But after weeks of one weird-gizmo demonstration after another, I want this one.

If a device like the Treo meets our communications needs, what about the need for a content-rich gadget that holds our files and our entertainment as we move from place to place? Perhaps the device that best captures the wave of the future today is Apple's iPod: a music player first of all, but with a five-gigabyte hard drive that early adopters are already using to carry along copies of their home hard drives, so that any Apple computer can be set up instantly to look like their own machines. Other makers of digital devices are following suit, adding storage and memory to digital cameras and MP3 players and improving short-range wireless connectivity so that these devices can easily grab content to go from their owners' personal computers—in effect, creating a convenient way for consumers to carry their digital worlds around with them.

Step 4—Back to the Drawing Board

Spend some time with human-factors experts and you begin to understand the tendency of research engineers not to listen to them. Engineers often get excited about what they *can* build, whether or not it's useful or usable. But human-factors experts are suggesting a more restrained approach, one that acknowledges our human needs and limitations first, before coming up with the innovations.

Which leads to some harsh conclusions: That in spite of an industry-wide assumption that pen-based computing is in our future, humans seem hellbent on being able to type a key and be certain of a result. That in spite of the obvious appeal of speech recognition, we're still going to prefer typing to that, too, until voice-activated technologies are just as trustworthy. That for all the hype about wireless delivery of broadband content, there's little evidence that users will suddenly want such material.

In trying to make gizmos that have a shot at becoming as popular as today's cell phones or PDAs, human-factors engineers have their work cut out for them. They will need to make their products small yet powerful; light yet durable; able to perform multiple functions but without burdening us with undue complexity. Most current designs treat these demands as contradictory—how can a device be both multifunctional *and* easy to use? Or small *and* powerful? Or portable *and* durable? But designs like the Ideo laptop and the Handspring Treo go a long way toward proving that it's possible to give people everything they want, given proper attention to usability.

In the last few years we've already seen many technologically sophisticated, hard-to-use gizmos fail. Once there was the Modo, a keychain-sized device that displayed information about restaurants on a tiny screen. No one bought Modos, and the company ceased production in October 2000. 3Com built Audrey, a digital organizer for the masses, which swiftly tanked. Whole subgenres of gizmos, such as portable Internet radios, have virtually disappeared. Each device failed because it offered a solution to a problem that wasn't there.

If those who propose a human-centered design approach are correct, we're about to see a whole new wave of product failures. But we're also about to see some quiet but life-changing successes—devices that give us what we need and that make our lives easier. Focusing on the things people will want to carry, rather than what we're able to build in a research lab, doesn't mean that engineers will have to stop being inventive. It just means they'll need to start thinking more about what people want—*before* deciding what to invent. TR

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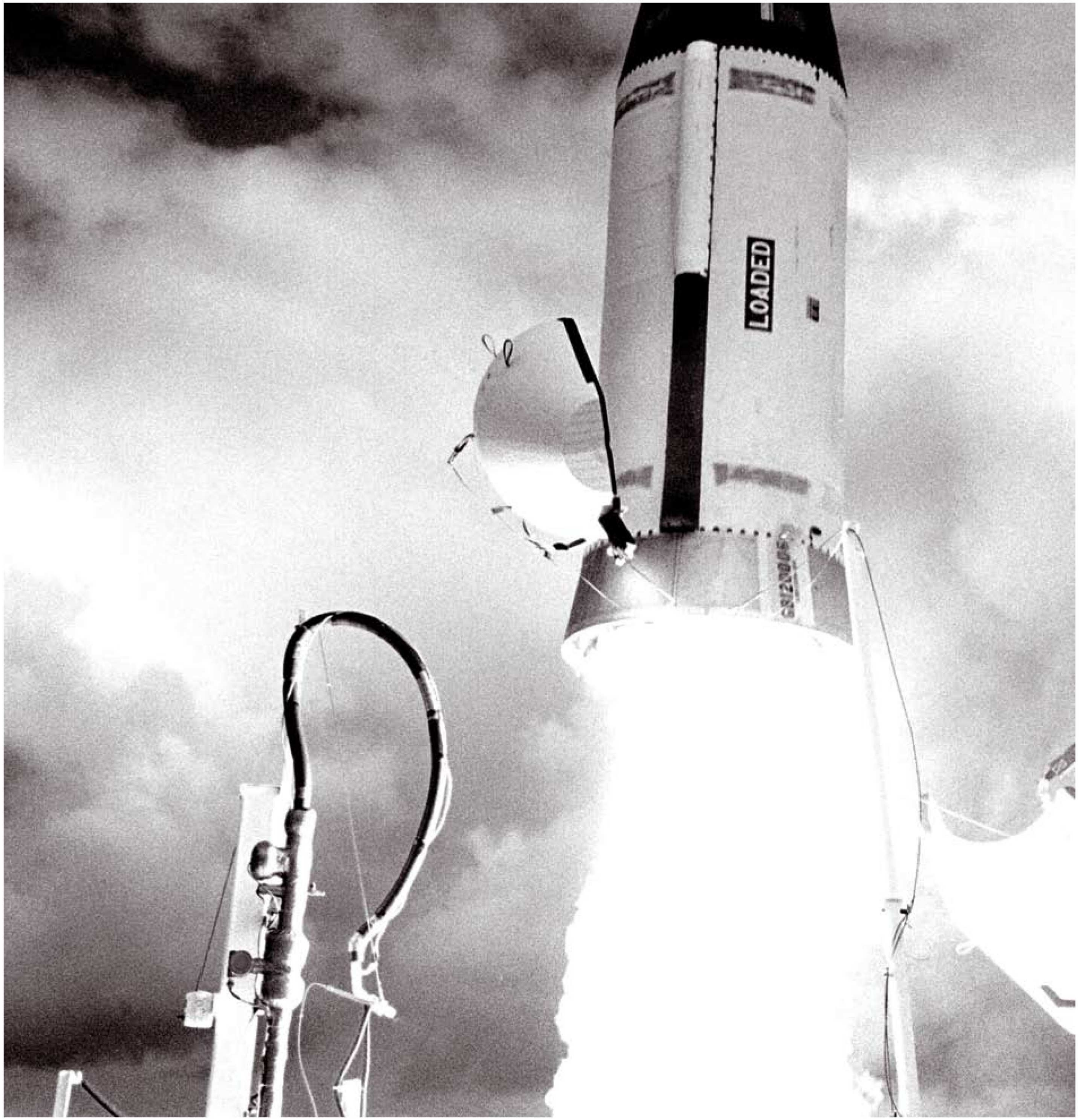
AN ANALYSIS OF U.S. MISSILE DEFENSE TESTS BY A LEADING EXPERT REVEALS THE BASIC FLAWS THAT WENT UNREPORTED—AND HOW A PRIMITIVE ADVERSARY CAN DEFEAT THE SYSTEM WITH THE SIMPLEST OF TECHNOLOGIES.

Why Missile Defense Won't Work

BY THEODORE A. POSTOL
Information Graphics by John MacNeill



Rising to the defense: A rocket carrying an "exoatmospheric kill vehicle" lifts off to intercept a mock warhead over the Pacific.

On June 23, 1997, a prototype of a U.S. military "kill vehicle" designed to intercept nuclear missiles lifted off from a launch pad on the South Pacific atoll of Kwajalein. Its purpose was not to seek out and destroy. Instead, it was to fly by and observe a group of objects that had been launched into space more than 20 minutes earlier from Vandenberg Air Force Base near Santa Barbara, CA, almost 8,000 kilometers away—and determine whether it was possible to distinguish a cloud of decoys from the mock warhead they protected.

It was a big day for nuclear missile defense. Since the decoys used in this experiment were of very simple design, if the experiment showed that the warhead could not be reliably identified, it could mean the whole Star Wars defense plan would for all practical purposes be unworkable, since the most primitive of adversaries could defeat it with the simplest of decoys. Of even greater importance, it would also be a clear demonstration of the fundamental physical reasons why any missile defense that relied on kill vehicles of this type could never be successful.

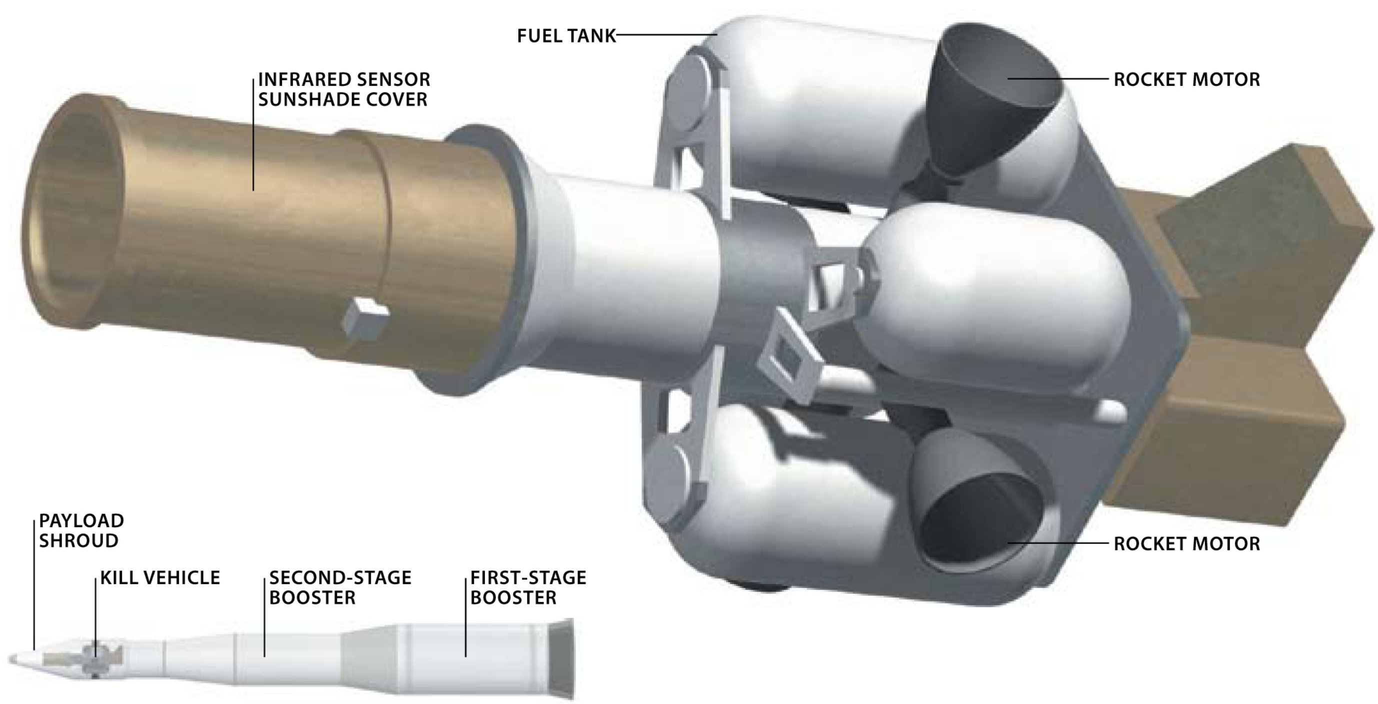
It worked—at least that's what we were told. But shortly after the experiment flew, three courageous people—a former employee of defense contractor TRW turned whistle-blower, a TRW retiree and a U.S. Department of Defense investigator—brought new evidence to light *(see "Postol vs. the Pentagon," p. 52)*. Their information, coupled with my own investigation and repeated calls for a full accounting from U.S. representatives Howard Berman and Edward Markey, pointed to a different story—one of failure, a finding seemingly confirmed this February by a draft of a Government Accounting Office follow-on study, as reported by the journal *Science.* I believe that the top management of the Pentagon's Missile Defense Agency (previously known as the Ballistic Missile Defense Organization) and its contractors have misrepresented or distorted the results derived from the experiment and rigged the follow-on test program that continues to this day. These deliberate actions have hidden the system's critical vulnerabilities from the White House, Congress and the American citizens whom the missile defense program was supposed to protect.

HOW THE DEFENSE SYSTEM IS SUPPOSED TO WORK

As envisioned since 1996, the U.S. National Missile Defense effort consists of three main elements: infrared early-warning satellites, ground-based radars to precisely track warheads and decoys from thousands of kilometers away, and multistage, rocket-powered homing interceptor missiles launched from underground silos. The most critical element of this defense is the roughly 1.5-meter-long "exoatmospheric kill vehicle" that the homing interceptor deploys after being launched to high speed by its rocket stages. After deployment, the kill vehicle has about a minute to identify the warheads in a cloud of decoys as it closes on the targets at high speeds. To that end, it carries its own infrared telescope and has small rocket motors that enable it to home in on its prey. The kill vehicle does not carry a

The kill vehicle: the heart of national missile defense

The Raytheon-built exoatmospheric kill vehicle used to hunt warheads is carried into space by a Boeing rocket (inset) and launched toward the threat. Infrared sensors distinguish warheads from decoys through characteristic fluctuations in brightness. Small rocket motors enable the kill vehicle to maneuver to destroy its target by force of impact.



PREVIOUS SPREAD: COURTESY OF BOEING

warhead. Rather, it is designed to destroy its quarry by force of impact.

When an enemy missile is launched, it typically takes 30 to 60 seconds to reach altitudes where the infrared early-warning satellites can detect the hot exhaust from its engines. These satellites orbit at an altitude of 40,000 kilometers and can be kept over the same point on the earth's surface. Once two or more detect the rocket, they can crudely track it in three dimensions by stereo-viewing. However, the satellites can only see the hot exhaust from the rocket's engines, so their tracking ends abruptly when the engines shut down—an event that typically happens in space at between 200 and 300 kilometers in altitude.

Roughly three minutes after engine shutdown, the rocket's upper stage and the just released warhead and decoys rise above the horizon, where they can be tracked by radar. The radar systems originally planned for this task operate on a very short wavelength (three centimeters at a frequency of 10 gigahertz), which allows them to identify objects to an accuracy of 10 to 15 centimeters from many thousands of kilometers away. This makes it possible to observe distinct reflections from different surfaces—even the seams on an object as it tumbles through space. The spacing and intensity of these signals, and the way their echoes vary as the orientation of a target object changes, can in some circumstances be used to determine which object is a warhead and which a decoy. If all goes well, this information will be used to deploy one or more interceptors within about 10 minutes of an attack's being launched. The interceptors will fly to the defense, destroying their targets about 18 minutes after launch *(see "Space-based vs. boost-phase defense," p. 50)*.

That, at any rate, is how the system was initially supposed to work. President Bush's latest proposal does not include this high-resolution radar, making tracking and identification of enemy missiles harder and delaying the interception time. But even with the more advanced original system, big problems surround the scenario. For starters, an adversary could alter the reflections from decoys and warheads by covering surfaces and seams with wires, metal foil or radar-absorbing materials. These simple strategies would render the radar unable to reliably sort out warheads from their armadas of decoys.

Compounding this problem is a simple fact: in the near vacuum of space, a feather and a rock move at the same speed, since there is no air drag to cause the lighter object to slow up relative to its heavier companion. This basic vulnerability makes it even easier for an adversary to devise decoys that will look like warheads to radar or an infrared telescope observing them from long range.

What's more, an adversary would likely deploy decoys and warheads close together and in multiple clusters. Under these conditions, even if the radar could initially identify a warhead among all the decoys, it couldn't track it accurately enough to predict the relative locations of the different objects when the kill vehicle encountered them some eight minutes later. Consequently, the kill vehicle must be able to identify warheads and decoys without help from satellites, ground radars or other sensors. If it cannot perform this task, the defense cannot work. This is where the infrared telescope comes in—and it was really this critical part of the system that the June 1997 test was all about.

The government and its contractors, the author argues, failed to report crucial sensor problems and misrepresented or distorted the results of experimental trials. These actions, he says, have hidden the system's critical vulnerabilities from the American people.

HOW THE KILL VEHICLE IDENTIFIES WARHEADS

During a typical intercept attempt, the closing speed between the kill vehicle and targets is around 10 kilometers per second. If targets can be detected from a distance of 600 kilometers, that doesn't leave much time—a minute or less—to distinguish between warheads and decoys and maneuver to ram into the right target. The resolving power of the kill vehicle's telescope is quite limited, so all objects look like points of light. Still, the distinction can be made—by measuring the brightness of each object, and to some extent its wavelength or "color," which in turn can give clues to its infrared temperature.

If, for instance, one object is a tumbling, featureless sphere, no orientation will look different from any other, and its signal will be steady. However, if another object is of a different shape, the different faces it presents to the kill vehicle will show varying degrees of brightness as it tumbles end over end through space; a rod, for example, will be brighter when its more luminous side area is exposed to the telescope than when viewed end-on and will appear to the kill vehicle as a distant point of light that increases and decreases in brightness twice during each complete rotation. So if there is prior knowledge that one target is a tumbling rod and the other is a featureless sphere, it will be clear which is which.

That's the theory. The truth is more complicated. For one thing, measuring temperature with this infrared equipment is not possible when objects in space are observed close to the earth, because their signals are routinely contaminated by reflected infrared radiation from the planet's surface; they are further confused by such factors as the amount of cloud cover, time of year and which part of the earth the target is over.

Even without such earthly interference, the limited strategies available to the defense for distinguishing warhead from decoys put it at a disadvantage. For example, one simple way for an adversary to make discrimination impossible is to put the warhead inside a balloon and deploy it with many additional balloons of different sizes and surface coatings. The temperature of a balloon exposed to the sun can be drastically altered, as can the amount of infrared heat it radiates and reflects from the earth and sun, depending on its size and surface coating. Balloons of different dimensions and with differ-

ent coatings would each look slightly different. Since there would be no way to know why this was so, there would be no way to know which balloons were empty and which contained warheads—and discrimination by the kill vehicle's infrared telescope would be impossible.

This is the central point that backers of missile defense have not been able to circumvent.

So far, there have been seven tests, the most recent last December. In each case, a payload of targets has been launched by a modified Minuteman II intercontinental ballistic missile (ICBM) from Vandenberg Air Force Base toward Kwajalein. The target-carrying Minuteman completes powered flight in about three minutes and deploys a rocket-powered vehicle called the Multi-Service Launch System. This vehicle takes another four and a half minutes to deploy its payload, but only after rotating nearly 90 degrees so it can release the targets along a single downward direction in space. Since the kill vehicle telescope has a field of view roughly equal to that of a person looking through a soda straw (about one to two degrees), the payload deployment along a single direction assures that the targets will all be in its limited sights when they arrive at Kwajalein some 20 minutes later. Since simultaneous observation of targets is critical to quickly distinguishing decoys from warheads, this specialized deployment geometry gives the kill vehicle a significant advantage—one it is hardly likely to have in a real-world attack. (If, instead, the targets were deployed in many directions, the kill vehicle would have to slew between many clusters of targets, viewing each for tens of seconds to get the same readings. Even if it could identify the right target, there would likely not be time to maneuver and intercept.)

When the first flight test was performed, 10 targets were to be observed by the kill vehicle. These included a roughly two-meter-long, spin-stabilized mock warhead; two cone-shaped rigid decoys that were of roughly the same shape and size as the mock warhead; four spherical balloons (two with a diameter roughly equal to that of the base diameter of the mock warhead, and two about half that size); a small cone-shaped balloon; a large spherical balloon; and the upper rocket stage that deployed the decoys and warhead.

At first glance, it might seem that this ragtag collection of decoys is just what an enemy would throw at us. But since the makeup of these objects and the space-infrared environment in which they operated were fully known—all the tests have been carried out around the same time in the early evening, assuring that the geometry of the sun and earth are essentially the same in every experiment—it was possible, at least in principle, to predict how each would look to the kill vehicle. The predictions indicated, for instance, that the two medium balloons would have scintillating signals as bright as that of the spin-stabilized mock warhead, which had roughly the same diameter. Each of the rigid cone-shaped decoys was expected to look like a tumbling warhead. The large balloon and upper rocket stage were expected to look much brighter than all the other objects, while the small spherical balloons and the cone-shaped balloon would stand out for their dimness. Under these simplified conditions, and with detailed prior knowledge of the characteristics of each object, it must have seemed quite likely that the kill vehicle could pick out the "warhead" from among the decoy companions.

The results of the actual trial were quite unexpected, however, and must have been extremely disconcerting to then director of the Ballistic Missile

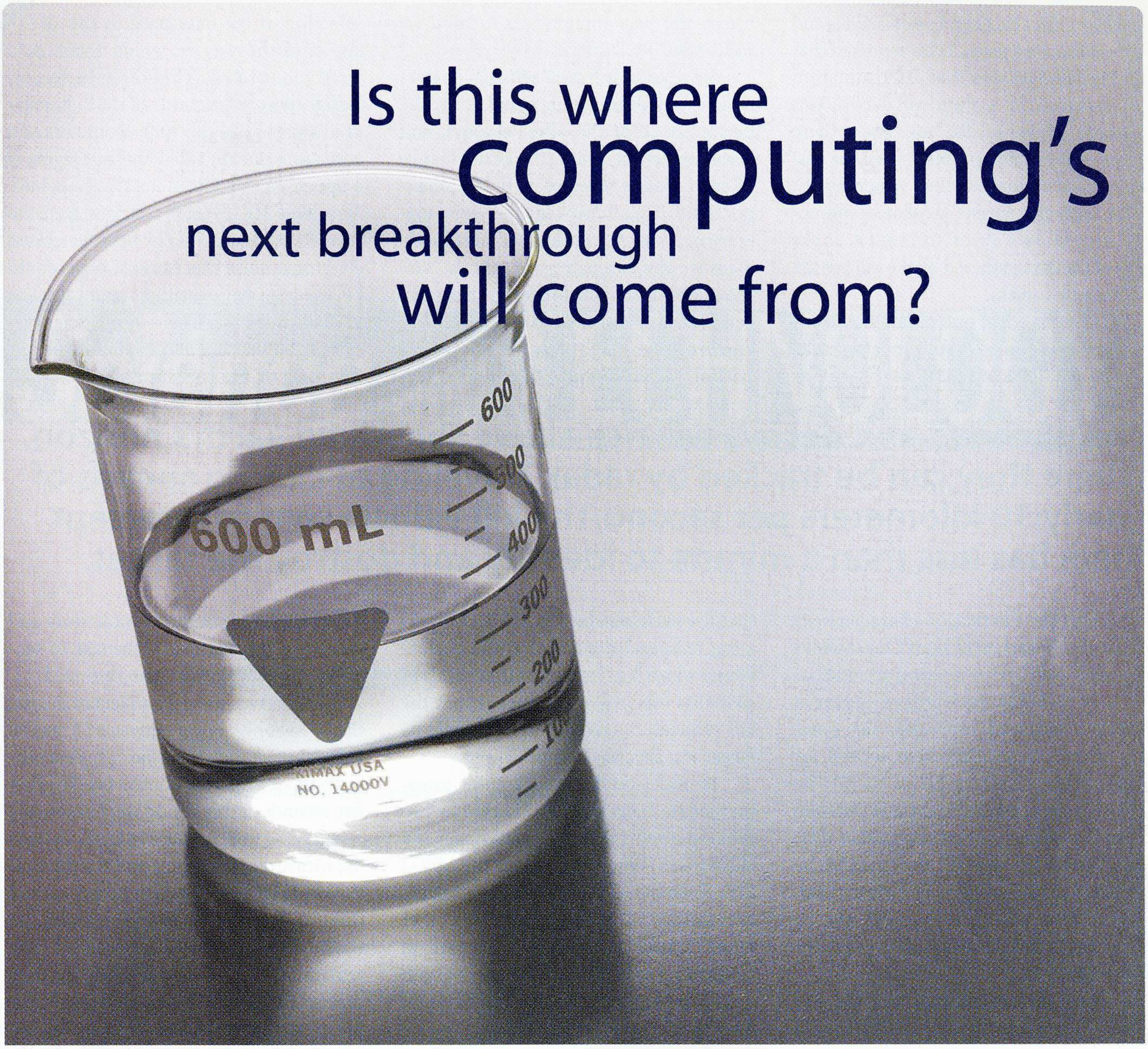
Dumbing down the decoys

One controversial aspect of the first U.S. missile defense trial is that several of the decoys successfully "fooled" the system into identifying them as the mock warhead. They were removed from subsequent trials.

MEDIUM STRIPED BALLOON
During the first trial, a balloon of this type failed to inflate completely and was briefly picked as the warhead.

CONE-SHAPED DECOY
One of a pair used in the first trial behaved differently than expected and was for a time chosen as the warhead.

LARGE STRIPED BALLOON
At 2.2 meters in diameter, this decoy looks many times brighter than the warhead. It was the only one kept for future trials.


Is this where
computing's
next breakthrough
will come from?
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Defense Office Lt. Gen. Lester L. Lyles and his engineering team. Lyles reported that the trial had proven that discrimination of warheads in a cloud of decoys was possible. However, we now know there was a serious basic problem with the first integrated flight test that would likely, even with the targets' expected characteristics known prior to launch, make any of the data gathered by the kill vehicle essentially useless.

To begin with, one of the medium-sized balloons failed to fully inflate, resulting in its looking half as bright as expected. The fluctuation characteristics of the mock warhead's signal, meanwhile, changed over time, making the probability of its being the warhead appear at different moments more than five times higher or lower than expected. Indeed, the fluctuation characteristics of all the objects were either substantially different from the predictions or changed in time so drastically that if they could be matched to the template of expected values at one time, they could not be matched to the same template even seconds later.

That was bad enough. But the real problem was that the kill vehicle's main infrared sensor failed to cool to its 12-degree-Kelvin design temperature, achieving instead a temperature no lower than 13.5 Kelvin. This difference is the same as if a space suit had been designed to keep an astronaut in a temperature environment of 20 °C but instead put her in an environment of 66 °C.

Since the sensor was very hot relative to its design operating temperature, the measured target signals were contaminated with heat-generated electronic noise. The unexpectedly high temperature also caused unpredictable changes in the efficiency with which each of the tens of thousands of tiny, independent infrared sensors in the kill vehicle converted infrared signals to electronic. These sensors are arrayed at the telescope's "eyepiece," so that an electronic image of the instrument's field of view can be formed, much the way images are formed by solid-state TV cameras.

Since each infrared sensor's performance was different in detail from the performance of the other sensors, and since the details of how the performance of each sensor changed with the unexpectedly high temperature were unknown, it was not possible to accurately measure the brightness of distant targets, or even the brightness of these targets relative to each other. Because knowing the brightness of a target is critical to identifying it, the singular fact that the main sensor was not at its operating temperature, and that the performance of each of its tens of thousands of elements was unknown, means that the kill vehicle's capacity to discriminate its target was severely compromised.

To understand this basic point, imagine that an object is being observed by two infrared sensors with different conversion efficiencies. When light from the object strikes one of the sensors, a certain brightness is recorded. When it strikes the other sensor, a different brightness is recorded. Unless the conversion efficiencies of both sensors are known, the actual brightness of the object cannot be determined.

This well-known problem and others associated with it would typically have been dealt with by calibrating the performance of each sensor over the range of expected operating temperatures prior to the experiment. However, the experimental team had not performed calibration measurements on the array at 13.5 Kelvin and higher because it had not expected such a massive failure in the sensor's cooling system. Additional sensor calibration data was supposed to have been obtained by observing an infrared star of known brightness, Alpha Bootes, but the noise in the many sensor elements, and changing sensor array temperature during the test, rendered this measurement useless.

So, I believe, when the carefully contrived test failed, the true results of the experiment were hidden through careful selection of the data used in the analysis—and the way in which those data were interpreted. The kill vehicle collected about 63 seconds of data, starting at a range of roughly 460 kilometers and continuing until it flew by the targets at a speed of 7.3 kilometers per second. The first 30 seconds of data were so severely contaminated by heat-generated electronic noise that none of them could be used in the postflight analysis. For various other reasons—some scientifically legitimate, but also including the fact that one of the medium-sized balloon decoys suddenly began to look more and more like the warhead—the last 16 seconds of the flyby were also removed.

That leaves the data collected during the 17-second period between 33 and 16 seconds prior to flyby as the only data officially reported by the contractor. The first five seconds of this period were eventually excluded as well, because changes in both the measured brightness and the fluctuation in brightness of each target caused three different targets to look like the warhead during this short interval. The remaining 12 seconds, then, were the only time when the signals were sufficiently stable that the observed data could be matched to a template of expected warhead and decoy characteristics. But because the sensor measurements involved unknown conversion efficiencies, and it was therefore impossible to use the original template, a new template was created after the test to fit the uncalibrated sensor data. It was this after-the-fact template, matched to almost certainly inaccurate measurements, that formed the basis of the claims about the experiment's success.

Such claims, it almost goes without saying, are meaningless.

The warhead and decoys will rise above the round earth's horizon, where they can be tracked by radar. Traveling at closing speeds of nearly 10 kilometers per second, the kill vehicle sent to intercept them has less than a minute to identify and destroy the target.

INSISTING ON SUCCESS

As I have noted, in spite of the numerous and fundamental experimental failures in the first trial, TRW and the Defense Department reported that the experiment was an unqualified success.

concealed from the American people and Congress the fact that a weapon system paid for by hard-earned tax dollars to defend our country cannot work.

HOW A SUCCESSFUL MISSILE DEFENSE SYSTEM MIGHT WORK

Whether or not one believes there is any threat serious enough to require deployment of a national missile defense, it makes no sense to advocate a concept that will not work. There is a way, though, to provide a defense that would likely be highly effective, a strategy that avoids the serious and as yet unsolvable problems posed by space-deployed decoys that I have discussed.

A "boost-phase" missile defense would target intercontinental ballistic missiles in their first few minutes of flight, while they are still being accelerated up to speed by their rocket engines. Because such a system would consist of very fast, short-range (perhaps a thousand kilometers) interceptors positioned only a few hundred kilometers from the "rogue" nations likely to attack the United States, it would be effective only over a relatively small region of the earth. While the system would be devastating when used against geographically small emerging missile states, it would be largely useless against missiles launched from vast countries such as Russia or China; it would simply not be feasible to position enough interceptors close enough to their launch sites. This is good news too, however, since it would allow the U.S. to target the Third-World states it claims to be most concerned about without provoking negative reactions from Russia and China.

In the case of North Korea, ships or converted Trident submarines could serve as launch platforms for these interceptors. Silos deployed in eastern Turkey would be effective for covering launches from inside Iraq. If a defense were required against Iran, its larger size and location would require defense sites in Turkey, Azerbaijan, Turkmenistan or the Caspian Sea.

When an ICBM was launched, it would be detected and tracked by sensors on the ground, in unmanned aircraft, aboard ships or on satellites. The interceptors would accelerate to 8 to 8.5 kilometers per second in a little over a minute. At these speeds, even if their launch were delayed for a minute or more in order to establish the enemy missile's trajectory, the interceptors could still destroy the ICBM while it was in powered flight, causing its warhead to fall far short of its target.

A "boost-phase" missile defense would consist of very fast, short-range interceptors positioned close to "rogue" nations. By targeting intercontinental ballistic missiles in their first few minutes of flight, this system would be much more reliable and harder to counter.

Unlike the proposed space-based system, this defense would be difficult to counter. Countries seeking to defeat it might try to reduce the boost-phase flight time, thereby narrowing the window of opportunity for a successful intercept. But that would require the development of highly advanced solid-propellant ballistic-missile technology—an innovation that is in a completely different league than the liquid-fuel, Scud missile technology that is currently the foundation for the missile programs of North Korea, Iran and Iraq. In addition, the technology needed to implement this defense is far less demanding than that needed for midflight intercepts in space. Because boost-phase interceptors would only need to detect the very hot plume of the booster and not the cooler warhead or decoys, such interceptors could use higher-resolution short-wavelength sensors that are easier to build and much less costly than the long-wavelength sensors used by the exoatmospheric kill vehicles of the planned nuclear-missile defense system. Finally, the ICBM booster target is large and would be destroyed by a hit almost anywhere, so the probability of a successful intercept would be very high.

Some boost-phase defense systems would certainly face significant geopolitical obstacles. Getting countries such as Azerbaijan or Turkey, for instance, to allow basing of interceptors in their territory could be a challenge. If a deployment against Iran were needed, it would also require close cooperation between Russia and the United States, which would likely increase existing Chinese concerns about a U.S.-Russia alliance.

However, these and other problems are all far more manageable than those raised by the currently planned space-based nuclear-missile defense system. Even the first phase of this fragile and easily defeated defense is threatening to create serious problems with both Russia and China—while providing the U.S. with essentially no meaningful protection against them or any other potential enemy state.

A PLEA FOR SCIENTIFIC AND POLITICAL LEADERSHIP

In the wake of the terrifying attacks on the World Trade Center and Pentagon, the entire civilized world will need to work to defeat the forces of ignorance, intolerance and destruction. In my view, the current attitude of the Bush administration that "we can go it alone" is one of the most dangerous and ill-considered security policies to be adopted and pursued by the United States in recent memory.

The current U.S. approach to missile defense is a direct outgrowth of the irrational idea that "we" can deal with the world without working with others. It is not only an irrational position when examined in terms of social realities, it is also irrational in terms of basic principles of physical science. It is sad and disturbing that the most technologically advanced and wealthy society in human history has displayed so little scientific and political leadership on matters that will almost certainly affect every aspect of global development in the 21st century. TR

Theodore A. Postol is professor of science, technology and national security policy at MIT

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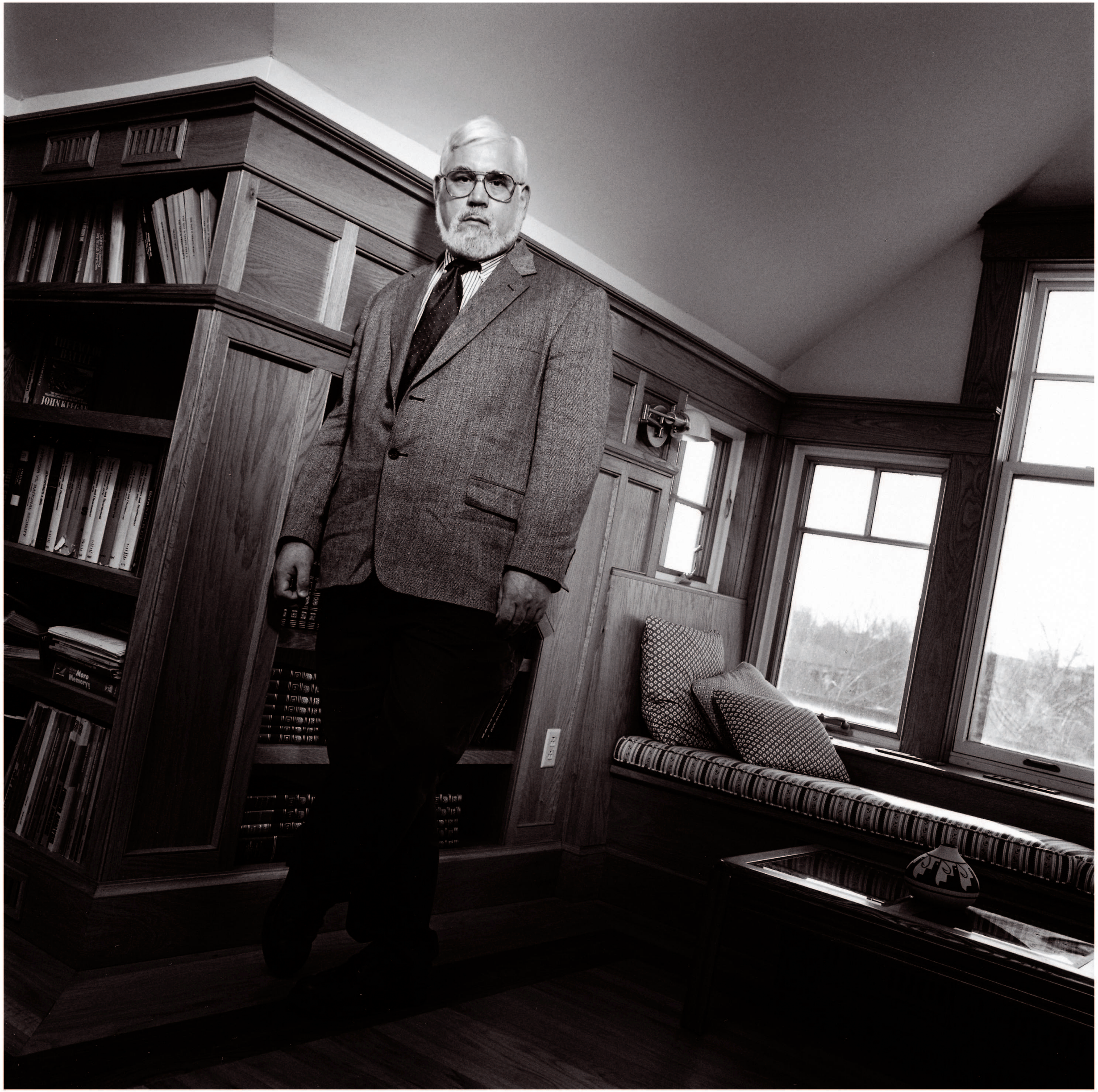
AN MIT PROFESSOR WHO ALIENATES EVERYONE IN HIS PATH SEEMS TO HAVE THE INSIDE TRACK TO THE TRUTH ABOUT MISSILE DEFENSE TECHNOLOGY. BUT THE GOVERNMENT DOESN'T LIKE HIS PESSIMISTIC CONCLUSIONS.

Postol vs. the Pentagon

BY GARY TAUBES
Photographs by Mary Ellen Mark



Going Postol: MIT professor Theodore Postol has made a crusade out of exposing the flaws of national missile defense technology.

It is conceivable, as one of his colleagues has suggested, that Theodore Postol could be more effective "if he did not eventually accuse just about everybody of fraud or malfeasance or stupidity." Over the past two years, for instance, the MIT professor of science, technology and national security policy has publicly accused the defense technology corporation TRW of perpetrating a hoax on the U.S. government. He has charged the Pentagon's Missile Defense Agency (formerly known as the Ballistic Missile Defense Organization) with committing an "elaborate scientific and technical blunder," compounded by fraud and misconduct. He has charged the authors of a report investigating those alleged frauds—who include two staff scientists at MIT's Lincoln Laboratory—with committing scientific fraud themselves to cover up the frauds they were allegedly investigating. He has charged the Pentagon's Defense Security Service, in a letter to John Podesta, who was then President Clinton's chief of staff, with "Soviet thuggish-style conduct." And he has even accused MIT president Charles M. Vest of doing little or nothing to clarify the matter or investigate.

This steady stream of indignation and accusation has led Postol's colleagues to describe him as not so much interested in building coalitions or playing politics as he is in pursuing the truth with a single-minded, laserlike focus. They also suggest that his passion and his capacity for outrage constitute his best and worst qualities. His volatility leads him into conflicts that detract from his main point, which happens to be one of extraordinary importance. Postol is asserting that the U.S. government is on the verge of deploying a $60 billion missile defense system that cannot possibly work—a move that would make the world a considerably less secure place to live.

But Postol's passion is also what motivates him to risk career and reputation every time he decides that the U.S. Defense Department—or all too often, MIT, his own institution—is pushing dubious technology on the American public. More than anything, it's that passion that drives his research, which has repeatedly proven to be dead on when it comes to assessing the failings of antiballistic-missile defense systems. So it is that most of his fellow specialists in defense technology believe that if Postol says the missile defense program has critical flaws, it probably does—and the nation should take notice.

Postol's technical analysis of missile defense is "the best work that anybody has done outside the bowels of the Pentagon," says former assistant secretary of defense Philip Coyle, the director of defense operational test and evaluation during the Clinton administration. Coyle makes what may be the salient point about Postol's role: when Postol is not publicly charging someone in the government-industrial complex of fraud or malfeasance or stupidity regarding missile defense, public discussion on the technology seems to grind to a halt. "When Ted is not in the news every month," says Coyle, "nothing happens."

The notion of a missile defense shield has been controversial since its earliest incarnation 40 years ago, when both the United States and the Soviet Union were actively developing such systems. Unlike Ronald Reagan's Strategic Defense Initiative of the 1980s, which sought to protect the country from a massive attack from the Soviet Union, current goals are more modest—and more achievable.

The idea behind "national missile defense," as it's now called, is to guard the United States against any stray missiles that might be launched accidentally by the Russians or former Soviet states, or with intended malice by terrorist groups or a rogue nation such as North Korea. The centerpiece of those defenses would be a system of missiles—known in the lingo as "exoatmospheric kill vehicles," or just "kill vehicles"—that would track down incoming warheads while they are still in the upper atmosphere and destroy them on impact.

Ted Postol happens to be one of many experts who have grave doubts that such a feat of technological virtuosity—often described as hitting a bullet with a bullet—is possible, or at least sufficiently probable to bet our national security and tens of billions of dollars on. "If you're going to build weapons," he likes to say, "they ought to work." And the kill vehicles, by his assessment, most likely will not work.

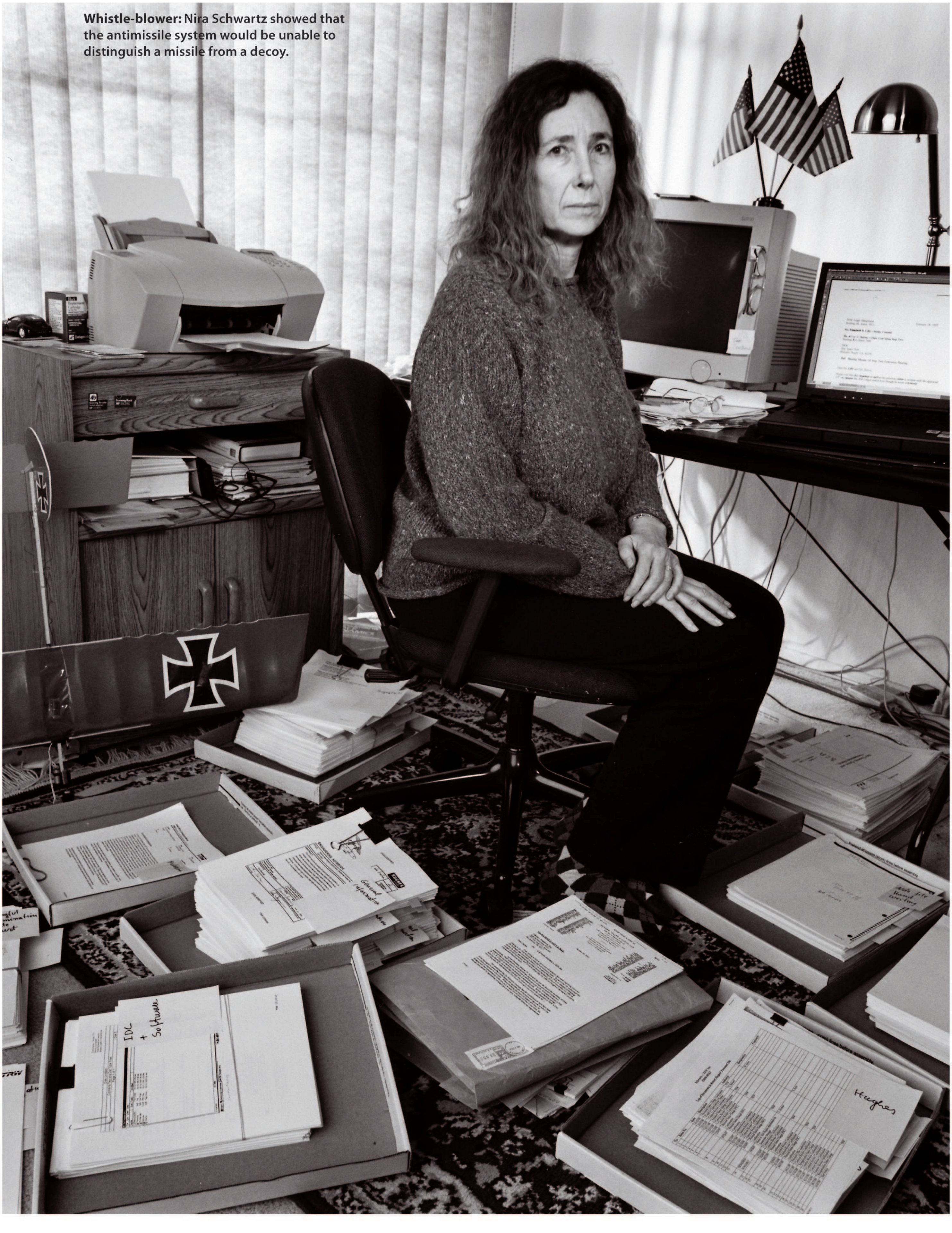
This adds a moral dimension to his outrage: if the government insists on deploying a dysfunctional missile defense system and believing—or at least pretending to believe—that it works, thousands or even hundreds of thousands of people could get killed. Anyone who knows better and doesn't actively work to expose the truth is culpable, Postol believes. As he recently wrote in a characteristically irate letter to President Vest, failure to speak out under these circumstances is morally equivalent to the decision of a structural engineer who knows otherwise to "[tell] the occupants of the burning World Trade Towers, 'Don't worry, the buildings won't collapse.'"

PATRIOT GAMES

Ted Postol's credentials as a serious analyst of military defense systems are impeccable. Trained at MIT as a nuclear engineer, he spent five years doing basic physics research at the Argonne National Laboratory in Illinois before moving to Washington in 1980 to work with the U.S. Congress's Office of Technology Assessment. At the time, he says, he believed the steadily growing U.S. and Soviet nuclear arsenals "would get us all killed" and that Washington was where his influence could help avert this fate. He spent two years at the technology assessment agency analyzing, among other things, deployment of the MX nuclear missile, and another two working as senior scientific advisor to the chief of naval operations in the Pentagon.

In 1984, he moved to Stanford University, lured by physicist and national-security expert Sidney Drell to work at Drell's new Center for International Security and Arms Control. Drell describes Postol as "a unique resource for doing hard-nosed, accurate, reliable and important technical analysis of military systems." Drell also says he has never known Postol to be wrong on an important issue. The respect is mutual. When Drell resigned from the Stanford program in 1989, Postol left as well, moving on to his current position at MIT.

Two years later, when the Gulf War broke out, Postol made his first overtly public appearance as a whistle-blower



Whistle-blower: Nira Schwartz showed that the antimissile system would be unable to distinguish a missile from a decoy.

on the issue of antiballistic missiles. The subject was the Patriot missile system, which won near universal acclaim for what appeared to be its remarkable ability to shoot down the Iraqi Scud missiles. In the few short months of the war, according to the official U.S. Army tally, Patriot missiles shot down 45 of the 47 Scuds that they were sent forth to engage. As a result, the Patriot had become what the press would call "Exhibit A" in the push for a national missile defense program and, in the words of the first President Bush, "proof positive that missile defense works." A convinced Congress promptly doubled the funding for national missile defense, allocating more than $800 million in 1992.

But Postol was skeptical. Using as his primary data televised video of Patriot-Scud engagements, he asserted that the Patriot almost certainly missed all the Scud warheads at which it was fired. Simply put, "The Patriot didn't work," says George Lewis, who worked with Postol on the Patriot analysis and is now associate director of the Security Studies Program at MIT.

Pentagon officialdom was not amused. The Defense Department launched an investigation into whether Postol had committed security violations and slapped a classified rating on his 1992 article in *International Security*, the journal in which he made his case against the Patriot. Raytheon, the Lexington, MA-based company that built the Patriot, also attacked Postol's credibility and his analysis. Raytheon officials accused Postol of doctoring the video footage to make his point, and then claimed that his analysis was fundamentally worthless.

In the end, Postol's assessment of the Patriot's performance would be vindicated, but it would take years. Even the Pentagon eventually admitted that the Patriot had failed (though Raytheon still insists otherwise), while an independent American Physical Society panel reported in April 2000 that the criticisms of Postol's analysis had been "without merit."

Along the way, Postol's relationship with MIT took a beating. A series of episodes, each relatively minor in itself, led Postol to conclude—and the local press to report—that the MIT administration was less interested in defending members of its faculty (i.e., Postol) than it was in protecting its relationship with Raytheon, a company that generously supported the university. In the midst of the controversy, for instance, and in the midst of Raytheon's attacks on Postol's credibility and analysis, MIT appointed Raytheon CEO Dennis Picard to the advisory board of Lincoln Laboratory—an MIT-owned lab that conducts R&D on a range of defense technologies.

"If you're going to build weapons," Postol likes to say, "they ought to work." And by his assessment, the antimissile "exoatmospheric kill vehicles" being developed for a proposed national missile defense system will most likely not work.

MISSING THE TARGET

Postol's latest exercise in missile defense whistle-blowing began a continent away in Redondo Beach, CA, and then moved along its own convoluted course for five years before Postol took it on as his own personal cause. For Postol, the story of this intrigue would become the leverage with which he would try to force public discussion and oversight of national missile defense research in a world in which, as Democratic congressman Tom Allen of Maine says, "the devil is in the details, and the details are classified."

In this case, Postol acted as not so much a whistle-blower as a whistle amplifier. The first report of something wrong came from Nira Schwartz, a naturalized U.S. citizen from Israel and an expert on computer image analysis and pattern recognition. In 1995, TRW hired Schwartz to work on the software for an exoatmospheric kill vehicle that would in turn be built by Boeing, all under the auspices of the Pentagon's Ballistic Missile Defense Organization.

Schwartz's task was to test and evaluate the algorithms that the kill vehicle would use to track an incoming warhead and to discriminate it from a potential swarm of decoys. Such target discrimination is the single most critical technology for the success of any antiballistic-missile defense plan. If target discrimination can be done in real-world circumstances—if a speeding bullet can truly track a speeding bullet, regardless of whatever countermeasures the enemy bullet deploys—then an antiballistic-missile shield might indeed protect the United States from attack. If target discrimination cannot be done under those circumstances, however, then any national missile defense system will fail.

As Schwartz later testified, she realized the TRW programs were incapable of discriminating warheads from decoys when they failed to do so repeatedly in her computer simulations. She further concluded that warheads produced no particular "signature" of heat or radiation or movement that would ever uniquely identify them.

Schwartz's insistence that TRW and Boeing admit to the Ballistic Missile Defense Organization that the discriminator wouldn't work did not endear her to her employers; in early 1996, she was fired. She then filed suit in Los Angeles district court alleging that TRW had defrauded the U.S. government and seeking to recover damages for the government. (Schwartz sued under the False Claims Act, a law that allows private citizens to blow the whistle on people or companies that are defrauding the government—and get a cut of the award money should they win.)

In such a case, the U.S. Justice Department can choose to join the suit if its investigators decide the suit is valid. The Justice Department asked the Defense Criminal Investigative Service to look into Schwartz's allegations, and the service assigned Sam Reed to lead the investigation. Reed relied on Schwartz and other experts, including Roy Danchick, a senior TRW engineer who had also worked on the targeting software, to help him make sense of the complex scientific and technological issues.

Reed concluded that Schwartz's accusations had merit and that, as he later wrote to the Ballistic Missile Defense Organization, the TRW discrimination program "does not, cannot and will not work."

While Reed's investigation was in progress, the TRW software was put to its first $100 million flight test. In June 1997, the Boeing exoatmospheric kill vehicle was fired into space from a Pacific atoll to intercept a test missile that had been launched 20 minutes earlier from California. The kill vehicle wasn't supposed to actually intercept the missile—just fly by it. The mission was to test the ability of TRW's discrimination program to identify a mock warhead amidst a handful of decoys. Both the Pentagon and TRW would claim that the test was a success. But when Reed had Schwartz, Danchick and his other experts examine the data, they concluded otherwise. As Danchick would testify, the TRW analysis was "impermissibly manipulating" the data to get the right answer *(see "Why Missile Defense Won't Work," p. 42)*. As he described it to *Technology Review*, the researchers had "fudged, dry-labbed, manipulated and censored the data to get the result they wanted."

The army said the Patriot missile shot down 45 Iraqi Scuds during the Gulf War. Postol, studying video of the engagements, concluded that the Patriot missed every Scud it was fired at. Pentagon officialdom was not amused, but later had to concede that Postol was right.

TOUGH QUESTIONS

So far, the case was relatively straightforward—but it wouldn't stay that way. Reed's investigation prompted the Ballistic Missile Defense Organization to look more closely at TRW's technologies for distinguishing warheads from decoys. First, Huntsville, AL-based Nichols Research, an independent contractor to the missile defense organization, reported in December 1997 that while the TRW discrimination software was "no Nobel Prize winner," it nevertheless met the requirements of the government contract. This assessment had a caveat, however: the Nichols investigators reported that when they asked TRW tough questions about the discrimination program, they often got no answers.

But Reed, at the Defense Criminal Investigative Service, argued that Nichols was too dependent on the Defense Department to offer an unbiased view. He ordered a second investigation. This one was to be conducted by a group known as POET, which stands for "Phase One Engineering Team." POET dates back to the early years of the Reagan-era Strategic Defense Initiative, when it was founded to proffer just this kind of technical expertise on missile defense.

The POET report was a curious document. Superficially, it exonerated TRW, claiming that the company's discrimination algorithms "are well designed and work properly." But the report's data belied this conclusion. In fact, the data made clear that the discrimination algorithms had *not* worked during the June 1997 flight test. Further, the data indicated that the algorithms would work reliably in the future only if they knew in advance precisely what all the decoys and countermeasures would look like. As critics pointed out, a rogue nation or terrorist group would be unlikely to disclose the shape, number and characteristics of its decoys before launching a nuclear missile attack. Nonetheless, the POET conclusions convinced the Department of Justice not to join in the suit against TRW, leaving Schwartz to press the case on her own.

This was when Schwartz decided to get outside help, and the story hit the public. First, she contacted the office of Howard Berman, a Democratic congressman from California. Berman was the author of the False Claims Act of 1986—the law under which Schwartz was suing TRW for fraud against the U.S. government. Berman requested that the General Accounting Office investigate Schwartz's claims against TRW. Schwartz then approached William J. Broad, a reporter with the *New York Times* who covered defense technology.

After reading Broad's March 2000 page one *Times* story on the affair, Postol invited Schwartz to give a seminar to his Security Studies Program at MIT. Postol found her presentation compelling and spent a few weeks confirming and extending her conclusions.

In addition to noting the POET report's dubious logic, Postol also questioned its objectivity. The POET group was not truly independent, he said, because its members included two people from Lincoln Laboratory—an organization that received $80 million a year from the Ballistic Missile Defense Organization for national missile defense research. This was "clearly a conflict of interest," says Postol. "You don't even have to look at the science."

Then Postol decided to ratchet up the stakes. As he saw it, TRW had manipulated data to cover up the inability of its discriminator to discriminate. He also believed the POET report (an unclassified copy of which he had obtained from Schwartz) was suspect, since its data and analyses contradicted the summary statements exonerating TRW. "What you have here is a key document that itself is scientific fraud," says Postol, "and it's being used by institutions with oversight responsibilities [the Ballistic Missile Defense Organization and the Department of Justice] to abrogate their responsibilities."

KAFKAESQUE ENCOUNTERS

Postol wanted to force the Clinton White House to publicly address what he considered serious and perhaps fatal problems with the planned national missile defense system. "I quite coldly sat down and thought this through," Postol says. "My view, right or wrong, is that these people couldn't care less about the truth." So he would force them to act. If they didn't do what he considered the right thing, he would use his contacts in the press to expose the shortcomings in the system.

First, in May 2000, Postol sent a letter to Clinton chief of staff John Podesta describing the scientific issues behind

Laserlike focus: Postol's allegations of fraud have led to rocky relationships with the Pentagon and its contractors—as well as MIT.

the exoatmospheric kill vehicle and spelling out the alleged frauds, step by step. He pointed out the extreme importance of the underlying issue—the ability of the kill vehicle to discriminate an incoming warhead and put it out of action. He suggested that the White House assemble a truly independent team of scientists to review the accusations and to monitor future missile defense flight tests. And he sent a copy of his letter to Broad at the *New York Times*, who promptly wrote another story about the alleged cover-up.

When representatives less supportive of the missile defense program tried to obtain the FBI case report, however, they were told the case files were being reviewed for security reasons. (When *Technology Review* went to press, the files still had not been released.) What they did get was a superficial three-page summary that one congressional staffer said read like a "press release"; the document merely summarized the controversial issues and called the affair a scientific dispute.

Moreover, that document claimed that the FBI investigators had worked closely with those from the General Accounting Office. But the GAO study was still in progress, and the GAO investigators admitted to only minimal contact with the FBI investigators, as did Postol, Defense Department investigator Reed and TRW engineer Danchick. Indeed, Nira Schwartz says the FBI never contacted her at all. Congressman Berman was expected to publicly release a preliminary report on the GAO investigation by March. According to a report in *Science* magazine, the GAO stopped short of accusing TRW of defrauding the government. But the agency's investigators reportedly have concluded that the TRW missile test could not possibly have worked—if for no other reason then because an infrared sensor crucial to discriminating warheads from decoys had suffered a mechanical failure.

With the FBI having failed to clarify the issue, at least as far as Postol was concerned, he turned his attention to the MIT administration. Postol hoped to use MIT's relationship with Lincoln Laboratory, and the fact that two Lincoln Lab scientists had participated in what he thought of as the fraudulent POET report, to force an independent evaluation of the alleged fraud. Postol also wanted to force the school and the lab to live up to his own sense of intellectual and academic integrity. Postol says that he ran into Vest on a flight from Washington, DC, to Boston and briefed him on the POET report, the connection with Lincoln Laboratory and the implications for a viable national missile defense program. "He understood the points I was making," says Postol. "We were talking as two professors about technical matters. He then said he would look into it. I have been riding him since."

Vest speaks highly of Postol, calling him a "very smart, very savvy, very dedicated individual, motivated primarily by patriotism, who is concerned about the nature of U.S. defense technologies." Finally, last November, six months after his first meeting with Postol, Vest acknowledged to *Technology Review* that MIT provost Robert Brown was looking into the allegations and doing a preliminary investigation. Vest said, however, that Brown was proceeding with extreme confidentiality so as "to protect the privacy of all involved," which was why nobody had informed Postol that such an investigation was in the works.

If the government insists on deploying a dysfunctional missile defense system, Postol says, thousands or even hundreds of thousands of people could get killed. Anyone who knows the truth and doesn't actively work to expose it is culpable.

At this point, the episode starts to play like a reprise of the Patriot affair. First, the Pentagon responded to the *New York Times* articles by classifying both Postol's letter to the White House and the formerly unclassified POET report. Then a trio of agents from the Defense Criminal Investigative Service appeared at Postol's MIT office attempting to get him to read a classified letter that would allegedly explain why his letter to Podesta had been classified. During what he calls a Kafkaesque encounter, Postol refused; he figured that the agents wanted to reveal classified information so that his security clearance would prohibit him from discussing information he already knew from unclassified sources. Postol says the Pentagon had used a similar ruse during the Patriot episode and that he had seen through it then, too.

Congress responded by raising Postol's accusations in a series of hearings on national missile defense. Congress also launched more investigations, including one by the FBI. In May, Congressman Curt Weldon, a Pennsylvania Republican who avidly supports missile defense, reported to Congress that the FBI had completed its investigation and had exonerated both TRW and the Pentagon. The FBI concluded that the charges were simply a "scientific dispute" and that "Postol's attempts to raise it to the level of criminal conduct had no basis in fact." Postol, Weldon said, "owe[s] the Department of Defense an apology."

TRW and the Pentagon, meanwhile, insist that Postol's charges are without merit and claim that every investigation so far, from the FBI on down, has exonerated them of wrongdoing. A TRW spokesman says the company is "pleased, but not surprised, at this vindication." The Pentagon echoes this line. "We are done with this," says Lt. Col. Rick Lehner, a spokesman for the Missile Defense Agency.

Postol isn't buying it. "This whole story has been one of every organization that has had a responsibility basically looking for a way not to do their job," he says, while he ticks off the names of the various organizations that chose to duck the issue rather than legitimately pursue an investigation. The list runs from the Defense Department to the Justice Department to the FBI and Congress and probably the GAO and, finally, to MIT. "It is," says Postol, "a failure of leadership at every level. It's a kind of shoddy work at every agency of the U.S. government with responsibilities. And now the president of MIT doesn't want to deal with the problem either. So it's going to escalate." TR

Marriage of disciplines: Stanford University's Harley McAdams and Lucy Shapiro helped unite engineering and biology.

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

the virtual cell

Biology and engineering are beginning to cross paths. At their intersection could come remarkable advances in the understanding and treatment of disease.

By Gary Taubes

When Harley McAdams was a few years shy of 60, he became a biologist. He had spent two decades of his working life as a systems engineer at AT&T's Bell Laboratories, and four years at Lockheed Missile and Space in Sunnyvale, CA, working on data systems architecture for military satellites.

In 1994, however, he took to attending biology seminars at Stanford University, where his wife, Lucy Shapiro, was chair of the developmental biology department. McAdams had his epiphany while listening to an eminent geneticist describe the complex biological circuitry that turns genes on and off in yeast. To the uninitiated, the diagram of this system was vaguely reminiscent of a plate of spaghetti, with various arrows and stop and go signs attached. To McAdams, it looked like nothing more than an electric circuit, with the kinds of feedback loops and regulatory and control mechanisms that constituted the meat and potatoes of his systems engineering work.

After the lecture, says McAdams, he and his wife made a deal. He would teach her Boolean algebra, the mathematical logic of computer circuitry, and in return she would teach him genetics. And so they spent the next year, or at least the nights and weekends, educating each other, until the day McAdams claimed that he could apply the rules of electrical circuitry—along with the computer modeling techniques engineers typically use to analyze and design such circuitry—to a genetic circuit. By so doing, McAdams was able to provide an understanding of how the genetic system worked that went far beyond what biologists had managed to achieve. "At one point, he just walked out of Lockheed and started working at home," says Shapiro. "I nearly had a heart attack."

By 2000, McAdams and Shapiro had published a seminal paper in the journal *Science* on the application of systems engineering to biology, and McAdams had acquired his own biology laboratory at Stanford University School of Medicine and funding from the U.S. Defense Advanced Research Projects Agency (DARPA) to pursue biological research. Even Shapiro began to view herself and her work in an entirely different light. "Now if somebody asks me what I do for a living," she says, "I say I am a biological systems engineer."

Shapiro and McAdams can be considered among the more senior members of the avant-garde of a revolution in biology, in which the immediate goal is to create computer simulations—styled after systems engineering—of the regulatory mechanisms of genes and, eventually, entire cells, tissues and organs. These simulations will allow researchers to do biology experiments "in silico," inexpensively and remarkably quickly. Ultimately, researchers will use such computer simulations to identify new drug targets and to design and screen new drugs that will lead to entirely new treatments—if not cures. "It's just a wholly new way of doing biology," says Jim Anderson, who directs a new program to fund such research at the National Institutes of Health.

confronting complexity

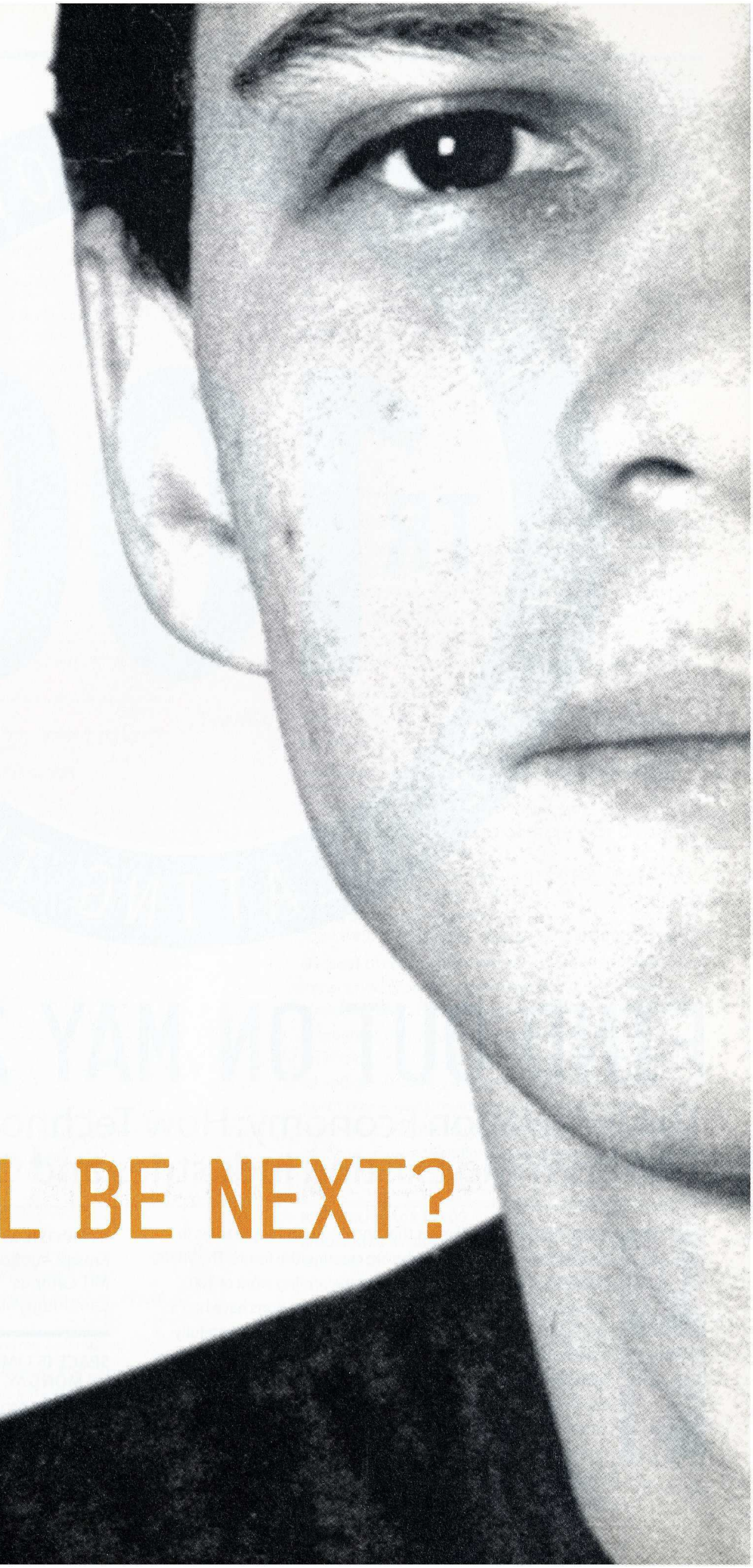
In the past three years, new departments and entire research institutes have been founded to pursue in silico biology at Stanford University, Caltech, Harvard University, the University of California, Berkeley, and the University of Washington, to name a few. All have the explicit goal of uniting biologists with physicists, engineers, mathematicians and computer scientists to create computer simulations that probe the outstanding problems of biology and medicine.

Forcing this in silico revolution are several inescapable facts: first is the sequencing of a host of complete genomes—the human genome being the most mediagenic—and the accompanying explosion in genomics technology. As a result, for the first time in history, researchers have what amounts to a genetic parts list for living organisms from bacteria to humans. This in turn has produced a shift in emphasis from the traditional focus of biology—"on intensive analysis of the individual components of complex biological systems," as Whitehead Institute biologists Eric Lander and Robert Weinberg recently described it in *Science*—to a focus on how those components work together in networks and entire cellular systems.

And finally, there's the fact that those cellular systems are awe inspiring, if not mind boggling, in their complexity. The flow chart of a relatively simple biological network, even when pared down to its most essential elements, looks like the wiring diagram for some demonic VCR. Genes encode proteins that interact with other proteins and perhaps other genes, all activated and deactivated by copious other smaller molecules and strung together into pathways—complete with various and sundry feedback mechanisms and redundancies. These networks then interact with each other in an equally bewildering, complex and interdependent manner. It is within this absurd complexity that a host of human diseases begin as simple wiring errors or failures in redundancy. Comprehending this complexity is far beyond the capacity of the unaided human brain. Add a little computer power, however, and the situation may soon change dramatically.

"By modeling these systems on the computer," says Adam Arkin, a professor of bioengineering and chemistry at Berkeley, "our ability to design drugs, engineer tissues, build new organs or even design bacteria for industrial uses is going to get a lot more rational. It may never be entirely rational—it will never be as rational as electronics—but it will be a lot closer."

What's more, says Caltech biologist Mel Simon, computer simulations provide researchers perhaps the only true test of understanding. Simon, for instance, spent over a decade working on one of the simplest and most comprehensively studied of all biological systems—the movement of bacteria toward or away from specific chemicals, a process known as bacterial chemotaxis. "By 1991 or '92," he says, "as a community, we had identified all the direct genes involved, and people were determining the structures of all the proteins, and I asked myself, at what point would I be able to say to the NIH,



THE YOUNG INNOVATORS
TR100
WHO ARE CREATING THE FUTURE

WHO WILL BE NEXT?

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2000 TR100 INNOVATOR OF THE YEAR

AGENDA

2002 TR100 SYMPOSIUM AND AWARDS CEREMONY

8:00 - 8:30 **Continental Breakfast**

8:45 - 9:30 **Morning Keynote**

CLAYTON CHRISTENSEN
PROFESSOR OF BUSINESS ADMINISTRATION,
HARVARD BUSINESS SCHOOL
AUTHOR, *THE INNOVATOR'S DILEMMA*

This session will provide you with a preview of what's new since *The Innovator's Dilemma*. Most people are convinced that the process of innovation is inherently afflicted by random events. While this is undoubtably true, Professor Christensen has come to believe that innovation is much less random than many have supposed. In his talk, he will describe the variables that affect the probability of success, which management can capably understand and control.

9:45 - 11:00 **Panel Discussion—Transformative Technologies**

MODERATED BY: CONSUELO MACK, CNBC
SPEAKERS TBD

This panel will reflect the scope of the TR100. CEO panelists from our core segments will discuss the power and relevance of these key technologies as engines of economic growth.

11:00 - 11:15 **Break**

11:15 - 12:15 **Security, Privacy and Technology**

MODERATED BY: STEVEN LEVY, SENIOR EDITOR, CHIEF TECHNOLOGY WRITER, *NEWSWEEK*

DAVID BOIES, FOUNDING PARTNER, BOIES, SCHILLER AND FLEXNER

KENNETH STARR, PARTNER, KIRKLAND AND ELLIS AND ADJUNCT PROFESSOR, NEW YORK UNIVERSITY SCHOOL OF LAW

NADINE STROSSEN, PRESIDENT, ACLU

New technologies allow individuals, corporations and government entities to monitor, track and identify employees, customers and the general public. *Technology Review* will provide a forum to discuss security and privacy in today's global economy.

12:15 - 1:30 **Lunch**

1:45 - 3:00 **Concurrent Afternoon Conversations**

These sessions will provide an in-depth perspective on the three industries that will have the most pronounced benefit from transformative technologies.

Session A **Personalized Medicine**

MODERATED BY: REBECCA HENDERSON, EASTMAN KODAK LFM PROFESSOR, MIT SLOAN SCHOOL

DARLENE SOLOMAN, DIRECTOR OF THE LIFE SCIENCE TECHNOLOGIES LABORATORY, AGILENT TECHNOLOGIES

KARI STEFANSSON, PRESIDENT AND CHIEF EXECUTIVE OFFICER, deCODE GENETICS

We've deciphered the human genome and moved into proteomics—the study of the individual proteins that the genes code for. Such advances anticipate the day when drugs are not only targeted at molecular workings or specific diseases but tailor-made for each individual's genetic makeup.

Session B **Beyond Pervasive Computing**

MODERATED BY: ROBERT BUDERI, EDITOR AT LARGE, *TECHNOLOGY REVIEW* AND AUTHOR, *ENGINES OF TOMORROW* AND *THE INVENTION THAT CHANGED THE WORLD*

RODNEY A. BROOKS, FUJITSU PROFESSOR OF COMPUTER SCIENCE AND ENGINEERING, DIRECTOR OF THE ARTIFICIAL INTELLIGENCE LABORATORY AND CO-DIRECTOR OF PROJECT OXYGEN, MIT

RICHARD RASHID, SENIOR VICE PRESIDENT, MICROSOFT RESEARCH

DAVID TENNENHOUSE, VICE PRESIDENT AND CORPORATE TECHNOLOGY GROUP DIRECTOR, RESEARCH, INTEL CORPORATION

Pervasive computing—the idea that wired and wireless computing services and applications will be available anytime/anywhere—is becoming realized. Now, computer scientists are taking the next step: promoting proactive, or attentive, computing, in which computers and sensors don't just respond to users, but anticipate their needs—through agents, data mining, sense-making and other software advances.

Session C **Breaking the Energy Deadlock—New Technologies for a Secure and Sustainable Energy Economy**

MODERATED BY: RICHARD LESTER, DIRECTOR, INDUSTRIAL PERFORMANCE CENTER AND PROFESSOR OF NUCLEAR ENGINEERING, MIT

FIROZ RASUL, CHAIRMAN AND CHIEF EXECUTIVE OFFICER, BALLARD POWER SYSTEMS

KURT YEAGER, PRESIDENT AND CHIEF EXECUTIVE OFFICER, ELECTRIC POWER RESEARCH INSTITUTE, INC.

BJORN STIGSON, PRESIDENT, WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT

Decades of controversy over access, environmental impact, and economic costs have created an energy landscape characterized by glacial change punctuated by periodic domestic and international crises. Can new technologies—from fuel cells to wind turbines, improved oil and gas discovery and production methods, and intelligent power grids, buildings and transportation systems—break the impasse and lead to a reliable, low-cost and environmentally responsible energy future?

3:00 - 3:15 **Break**

3:15 - 4:30 **Introducing the TR100**

MODERATED BY: BOB METCALFE, INVENTOR OF ETHERNET AND FOUNDER OF 3COM CORPORATION, PARTNER, POLARIS VENTURES

This panel discussion will vividly illustrate the power and future of transformative technologies.

4:45 - 5:15 **Announcement of the Innovator of the Year**

7:30 - 10:00 **Black-Tie Gala at the Hyatt Regency**
Cambridge, Massachusetts

Please note: Agenda subject to change. The sponsors and management of *Technology Review* reserve the right to make any necessary changes to this program. Every effort will be made to keep presentations and speakers as represented. However, unforeseen circumstances may result in the substitution of a presentation topic or speaker. Technology Review, Inc. reserves the right to use photographs or video of any TR100 attendee for future promotions.

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If you must cancel for any reason, we will need written notice of cancellation by Wednesday, May 1, 2002. Your registration will be refunded less a $100 processing fee. Cancellations after Wednesday, May 1, 2002, are non-refundable. You may transfer your registration to another person at any time by providing written authorization. Please send all cancellation and transfer notices to *Technology Review*, Attn: Sharon Morani, 1 Main Street, 7th floor, Cambridge, MA 02142. They can also be sent via fax to (617) 475-8042.

Press Information or Press Registration
For information on registering as a member of the press for *Technology Review*'s TR100 or to request press releases for this conference, please email Kristen Collins at Kristen@kmcpartners.com.

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Technology Review has secured a special group rate at:
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TR100 attendees will receive the special room rate of $179 for a single or double room. Rooms are available from Wednesday, May 22, through the evening of Friday, May 24, 2002.

To make your reservations, please call the hotel directly at (617) 492-1234 and reference *Technology Review* 2002. You can also make your reservations online at www.hyatt.com.

To secure the discounted rate, all reservations must be made directly with the hotel by April 22, 2002. Reservations made after the cut-off date will be made on a space availability basis. For more information visit the Hyatt Web site at www.hyatt.com.

REGISTRATION FORM

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which was supplying us with money, that the job was done—that we now understood chemotaxis? It was an epistemological question. How do we know we understand something? The only criteria we could think of was if we could split a video screen and have bacteria sitting on one side of the screen and have a computer model of how the population of bacteria should behave on the other side of the screen. If the two behave in the same way, if we change conditions and get the model to do what the real bacteria do, then we know we understand. And that's why we started doing it."

keep it simple

The point that the chemotaxis field reached in the early 1990s—where there was finally enough experimental data available to begin to think about computer simulations—has now been reached by all biology, says Simon. At the moment, most practitioners of in silico biology are starting with the simplest possible cells and the simplest possible systems and hoping to work up from there. The main exception to this rule is the handful of companies that have recently begun marketing simulations of complicated disease processes, on the level of organs and cells, to pharmaceutical companies *(see "In Silico, Inc.," this page)*. But the bulk of the work in academic research laboratories and biotechnology firms has targeted relatively simple systems, like bacterial chemotaxis, or particular cellular pathways that have been studied for decades and on which copious detailed information has already been collected.

From these simple systems, in silico biologists hope to identify what they have taken to calling "modules" or "control motifs" that are common to other types of cells—or even to all cells. Then researchers can begin hooking these modules together in ever more comprehensive simulations that begin to realistically approximate what's happening in entire cells.

"You look at a cell as composed of discrete cellular machinery," says Ravi Iyengar, a biologist-turned-modeler at Mount Sinai School of Medicine in New York. "You understand them one at a time and then eventually put it together. If we want to dream, we can say eventually we should be able to construct a simulation of a whole mammalian cell this way. We don't have the knowledge to do it now. But it's do-able."

This is the goal, challenging as it may be, faced by an ambitious new project known as the Alliance for Cellular Signaling and led by Nobel Prize-winning biologist Alfred Gilman of the University of Texas Southwestern Medical Center at Dallas *(see "The Proteomics Payoff,"* TR *October 2001)*. The alliance hopes to someday simulate all the "signal pathways" in two specific types of mouse cells—B lymphocytes, which are part of the immune system, and the heart muscle cells known as cardiac myocytes. One such pathway might, for instance, carry a signal from a hormone or a toxin outside the cell to the cell's nucleus, turning specific genes on or off. "Our long-term goal is to be able to watch the flux of information come through the pathways of the cell and see how those pathways control that flux," says Gilman. "And that ultimately becomes a model of what's happening inside the cell."

In Silico, Inc.

The computer simulation of biological processes may constitute the future of pharmaceutical research, but what about the present? Is the technology ready for prime time, especially in a business where a wrong decision on a drug development project can cost hundreds of millions of dollars?

A handful of companies—led by Entelos of Menlo Park, CA, and Physiome Sciences of Princeton, NJ—are betting that the answer is yes. Physiome, for instance, markets software for simulating cells, as well as an elaborate heart simulation program called CardioPrism. With CardioPrism, the idea goes, pharmaceutical and biotech companies can save money on human trials by first testing their heart drugs and their theories on a computer model of human heart tissue. Entelos markets a series of "PhysioLabs," customized software packages that attempt to integrate all the available scientific data into a model of a specific disease—asthma or obesity, for example—rather than a single cell or organ.

Both companies talk of their simulations as works in progress, preliminary models that will become more and more accurate with further experiments, data and modification. But the companies say that their software is useful even now. "The pharmaceutical industry has to make decisions every day under a vast degree of uncertainty about what's going on in disease states," says Tom Paterson, chief scientific officer at Entelos. "The rationale behind these decisions is by no means systematic; in some cases, decisions get made by who has the authority, or the loudest voice around the conference table. Instead, we're giving [drug companies] a systematic, defensible, rational way to put data together. Sure, our models will have missed stuff compared to the gold standard of someone having stashed away God's blueprint for asthma, for instance, written out to 10 decimal places. And our models are going to be wrong in some places. But that's fine, because the architecture is designed to evaluate multiple hypotheses."

The asthma PhysioLab project began in the late 1990s when researchers from Aventis Pharmaceuticals approached Entelos. The Aventis researchers then went about teaching their Entelos counterparts everything they knew about asthma. Since then, the model-building has moved forward collaboratively between the two companies.

So far, says Aventis research scientist Bob Dinerstein, Aventis has made no major drug development decisions based specifically on predictions of the simulation; but the software has given researchers ideas about which immune cells they should target and which areas of the lung are the most sensitive to slight restrictions in air flow. To Dinerstein, simulations are indeed the present and the future of the pharmaceutical industry. Back in the 1960s, he says, a company like Boeing had relatively simple computer simulations at its disposal, relying heavily on prototypes and test flights to develop new aircraft. "Now Boeing is designing 777s 'in silico,'" he says. Thanks to the growing biological-parts list generated by the Human Genome Project and other large-scale efforts, along with recent explosions in computing and storage power, Dinerstein says, "In the pharmaceutical industry, we're at the beginning of that same 35-year course."

To pull this off, Gilman and his collaborators have enlisted the help of 50 participating investigators, all senior researchers, and of another 300 researchers each of whom is an expert on specific molecules involved in the pathways. They've raised over $10 million a year in funding for the next 10 years, and have obtained space to build seven dedicated labs where researchers will work on every stage of the project, from preparing and analyzing cells to building new machinery for making the necessary measurements to doing the modeling itself.

Gilman acknowledges that the plan is highly ambitious—a "crazy idea," he says—but still believes that in only five years they can have a "pretty complete" parts list of the two cells and know "a hell of a lot about the complete dictionary" of interactions between the parts, and how the information flows through the cells. He seems equally proud of having managed to convince six pharmaceutical companies to contribute to the alliance. "We're putting all the data out [on a Web site] in real time for everyone's use," he says, "and making no claims to intellectual property. This makes it particularly interesting that we're getting money from the pharmaceutical industry. But if we really did understand signaling systems thoroughly, and if we had the equivalent of a piece of a virtual cell in terms of a quantitative model of all the signaling systems, that would be an incredible drug discovery engine and of great value to the industry."

One hypothetical way drug companies might use in silico biology, says NIH's Anderson, would be to find new drug targets, and maximize the effectiveness of drug candidates, by doing what's known in the jargon as a sensitivity analysis. In effect, the researchers would simulate signaling pathways that are known to lead to, say, cancer when they go awry. Then the simulation could tell the researchers exactly where a drug molecule could intervene to have the maximum effect on the errant pathways.

Another project, already under way in biotech firms, says Anderson, is to create computer simulations of the biological systems that bacteria, for instance, use to produce such bestselling antibiotics as erythromycin. "Antibiotics are usually synthesized by soil bacteria, and these use extremely elaborate biosynthetic pathways that have been very difficult for us to crack," says Anderson. "Every drug company would like to improve the yield of their most costly antibiotics by being able to deliberately engineer the bacteria to do x, y and z and to do it better. So what you want to do is simulate in silico the biological systems that regulate and control the synthesis of the antibiotics in the bacteria. Then you can learn how to modify the bacteria genetically in order to accentuate the production or change the characteristics of the particular antibiotic that you're already making."

More ambitious still, and perhaps another decade or more in the making, is the Digital Human Project, an inchoate national initiative that is just now taking shape in funding agencies in Washington, DC. The idea grew out of the Defense Advanced Research Projects Agency, says Shankar Sastry, former head of the agency's information technology office and now chair of the electrical engineering and computer sciences department at the University of California, Berkeley. The eventual goal, he says, is a "fully functional model of an entire human body from intercellular through the tissue level through the organ level right up to the functioning of the entire body."

Such a model would require at least as much effort and collaboration as went into the Human Genome Project and might cost a billion or more dollars a year to build. It would be used eventually for teaching—"every university in this country will be able to bring anatomy and physiology to life," says Sastry—and for pharmaceutical research. "If you have simulations you can trust," says Sastry, "you can try your drug out on the simulation to understand all its complex interactions." DARPA is now gearing up to spend $80 to $100 million on programs that would seed the necessary technologies to make such a digital human a virtual reality.

As the in silico revolution explodes through the biological community, those who have already caught the bug are confident that sooner or later everyone will be doing it—at least, says biologist Tom Pollard of the Salk Institute for Biological Studies in La Jolla, CA, "if they want to understand how any biology works."

Biologist Alfred Gilman says his plan to model cells is ambitious—"a crazy idea." But, he adds, "if we had a piece of a virtual cell, that would be an incredible drug discovery engine and of great value to the pharmaceutical industry."

Less certain, however, is how quickly the revolution will pay off. The handful of commercial endeavors selling simulations of tissues, cells or entire disease processes believe their models can already benefit pharmaceutical researchers by providing them, if nothing else, with a more structured way to think about the diseases they're attacking. But talk to enough biologists-turned-modelers or engineers-turned-biologists, and you'll get estimates ranging from a decade for a reasonable simulation of a simple cell to a century for an equally accurate simulation of a human from the genetic level on up.

Occasionally the discussions of the future of in silico biology take on a catch-22-like tone: the computer simulations will be indispensable tools for anyone who wants to truly understand the inner workings of cells, tissues and organs, but those computer simulations are going to be crippled until researchers can inform them with a better understanding of the cells, tissues and organs they're studying. Until then, progress will be made as both researchers and simulations bat new data and hypotheses back and forth between them and slowly converge on reality. "This is not a short path to glory," says Drew Endy, a civil-engineer-turned-biologist at Berkeley, CA's Molecular Sciences Institute. "This is a decades-long effort." TR

Bringing the body to light: The University of California, Berkeley's Shankar Sastry says a whole-body simulation would be a boon for teaching and research.

motorola's superchip

BY IVAN AMATO

photographs by misha gravenor

MOTOROLA CLAIMS TO HAVE BROKEN DOWN THE BARRIER BETWEEN SILICON AND MORE EXPENSIVE SEMICONDUCTORS. THE RESULT: THE SILICON IN YOUR CELL PHONE OR DVD PLAYER COULD GAIN EXTRAORDINARY POWERS.

Behind the discovery: Motorola's Jamal Ramdani developed a technique for making high-speed optical chips more affordable.

While lying on the beach during a vacation on the Spanish coast in 1999, physicist Jamal Ramdani had an epiphany. As the sand complied to the contours of his body, Ramdani, a researcher at Motorola Labs in Tempe, AZ, suddenly envisioned a solution to a puzzle that had perplexed the semiconductor industry for 30 years: how to combine cheap silicon with high-speed, light-emitting but far more expensive semiconducting materials like gallium arsenide, all on a single wafer.

Because the materials are physically mismatched, layering one on top of the other to produce a chip with optimal electronic and optical properties has been virtually impossible. It may have been the sand on that Spanish beach, which is made of the same mineral from which silicon wafers are derived, that provided Ramdani with the pivotal hint. In any case, Ramdani recalls, "I came back to Phoenix, borrowed a machine for growing compound semiconductors, and in two or three shots, we had gallium arsenide sitting on silicon."

The benefits of having the functionality of gallium arsenide—particularly its abilities to handle wireless communications and emit light—on an inexpensive silicon chip were not lost on Motorola executives. High-performance chips made out of gallium arsenide and other so-called compound semiconductors are widely used in everything from cell phones to switches in optical communications networks. At the very least, Ramdani's invention could mean replacing these costly chips with far less expensive gallium-arsenide-on-silicon ones. In the two years since Ramdani's breakthrough, Motorola has filed over 300 patents on the technology; last fall, the company used Ramdani's method to build prototype chips for boosting signals in cell phones. To commercialize the new material, Motorola has started up a wholly owned subsidiary—Thoughtbeam, in Austin, TX—promising the new materials will find their way into electronic and optical devices within the next two years.

The impact of Motorola's chip technology could go far beyond cheaper cell phones or optical devices. Today, if you want a fast, inexpensive microprocessor, you need a silicon chip; if you want a chip to handle optical functions or high-frequency radio signals, you need compound semiconductors like gallium arsenide or indium phosphide. As a result, equipment like cell phones and communications network switches requires multiple semiconductor devices. Eventually, predict some experts, the Motorola technology could make it possible to integrate the functions of gallium arsenide and silicon on a single chip, using each of the materials for what it does best. The result would be a superchip. Instead of having multiple chips in a DVD player doing different tasks—generating light to read the disc, fielding input from viewers, decoding digital data into images and sound—a single chip could handle it all.

The semiconductor industry has been dreaming of such a superchip for decades—and a number of researchers are actively pursuing that dream. For instance, Eugene Fitzgerald, a materials scientist at MIT, has been working on the problem for over a decade and has published descriptions of his own technique for growing gallium arsenide on silicon. He and many other skeptics question whether the Motorola technology will prove to be a grand slam. "Every few years, there is a so-called solution, but upon closer examination, you see that it isn't one at all," says Fitzgerald.

Others, however, are so impressed with the potential of Ramdani's breakthrough that they believe the technology could fundamentally change the dynamics of the chip-making business, finally bridging the materials divide between silicon and compound semiconductors that has become a fundamental fact in the industry. According to Steve Cullen, director and principal analyst of semiconductor research services at Cahners In-Stat Group, the Motorola advance could "go down in history as a major turning point for the semiconductor industry."

Silicon's Cousins

Silicon is the material of choice for the vast majority of chips used in microprocessing applications; it's easy to handle, and manufacturers have learned to carve into it the tiny circuitry that makes possible today's fast and inexpensive computers. But for all of its celebrity, silicon cannot match the wireless and optical capabilities of more expensive semiconductors like gallium arsenide and indium phosphide.

These materials are called "compound" semiconductors because their crystals—unlike silicon's—are composed of more than one element. This more complex composition often endows them with desirable physical traits. For instance, because electrons travel faster in many compound semiconductors, the materials can process higher-frequency radio signals and hence larger amounts of data, which is just what you need if you want, say, handheld wireless devices that can receive seamless streams of video.

And unlike silicon, many of these compound semiconductors can emit beams of light when fed just a little bit of electrical current. That makes possible the solid-state lasers that can read the small bits of information densely packed on a CD or DVD. High-speed optical communication networks also rely on compound semiconductors for converting optical information into electronic information, and vice versa, at the thousands of places where optical fibers meet electronic switches and computers.

However, the same complexity that makes compound semiconductors so useful also makes them brittle, hard to synthesize, tough to integrate with other materials—and very expensive. At the moment, a 15-centimeter wafer of gallium arsenide costs about $300, while a 20-centimeter silicon wafer can cost about one-tenth as much. Ramdani's breakthrough involves a way to deposit a patina of gallium arsenide atop a wafer of stan-

dard silicon. The top layer of gallium arsenide provides all the unique capabilities of that material, but putting it on a silicon substrate makes it much easier to handle and cheaper to manufacture.

At first blush, the procedure sounds about as simple as slathering peanut butter on top of a slice of bread. But in practice, it's much trickier. The fundamental problem, says Fitzgerald, is that the underlying crystalline structures of silicon and gallium arsenide are so different that layering one on top of the other is like stacking grapefruits on a bed of oranges. "You get misfits and extra spaces," says Fitzgerald. These defects in the crystal tend to snag electrons, disrupting the functions of the semiconducting devices.

So far, the mismatch problem has defeated just about anyone who has ever attempted to make gallium-arsenide-on-silicon wafers. That helps explain why many researchers at companies like IBM and the semiconductor technology startup AmberWave Systems of Salem, NH, are pursuing an alternative approach to more versatile and powerful semiconductors: tweaking silicon so that it behaves more like its fancier cousins. That way, they get the cost benefits of using the 50-year-old infrastructure of silicon manufacturing technology and yet still approach the performance of compound semiconductors.

AmberWave Systems, which was cofounded by MIT's Fitzgerald, has developed a form of "strained" silicon crystal in which electrons move faster than in regular silicon. The material makes faster transistors possible, and that means, for example, higher-frequency radio signal processors. The researchers grow a layer of a silicon-germanium alloy on top of a silicon wafer and then top the alloy with a thin layer of silicon. Because the distances between atoms in the silicon-germanium crystal are longer than in silicon, the silicon atoms in the top layer must stretch in order to match the spaces between the atoms in the silicon-germanium below. When the silicon atoms are farther apart, electrons move about more freely, hence faster.

In fact, this little bit of crystal engineering has yielded samples in which electrons move up to 80 percent faster than they do in ordinary silicon wafers. Within the next year, AmberWave hopes to see devices made from this material hit the market—microprocessors, for instance, or signal-boosting chips in cell phones.

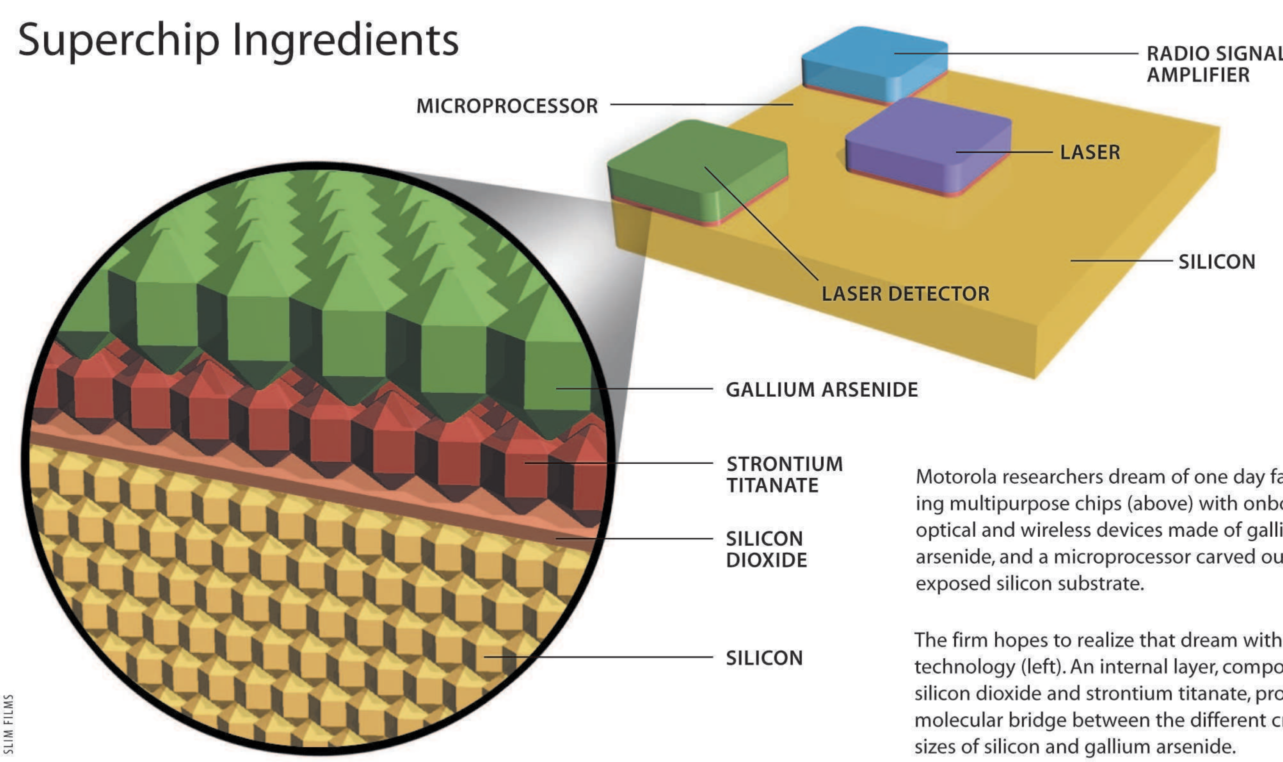
Vacation Visions

Tweaking silicon could make it faster, but for optical capabilities you still need compound semiconductors. While a number of researchers are trying to grow compound semiconductors on silicon, Motorola believes it has a head start in the race to commercialize the technology—thanks to both Ramdani and the company's well-established manufacturing and marketing infrastructure.

The history of Ramdani's breakthrough actually begins at least a year before his fateful Spanish vacation. Ramdani was part of a Motorola research group trying to make silicon faster when he made an accidental discovery that would lead to the gallium-arsenide-on-silicon project. At that time, he and his colleagues were focusing on the thin, glasslike layer of silicon dioxide that forms on top of silicon when it is exposed to oxygen during chip processing. This layer, known as a dielectric, is a vital chip component because it enables one transistor to control the electrical state of another while preventing electrons from leaking between them.

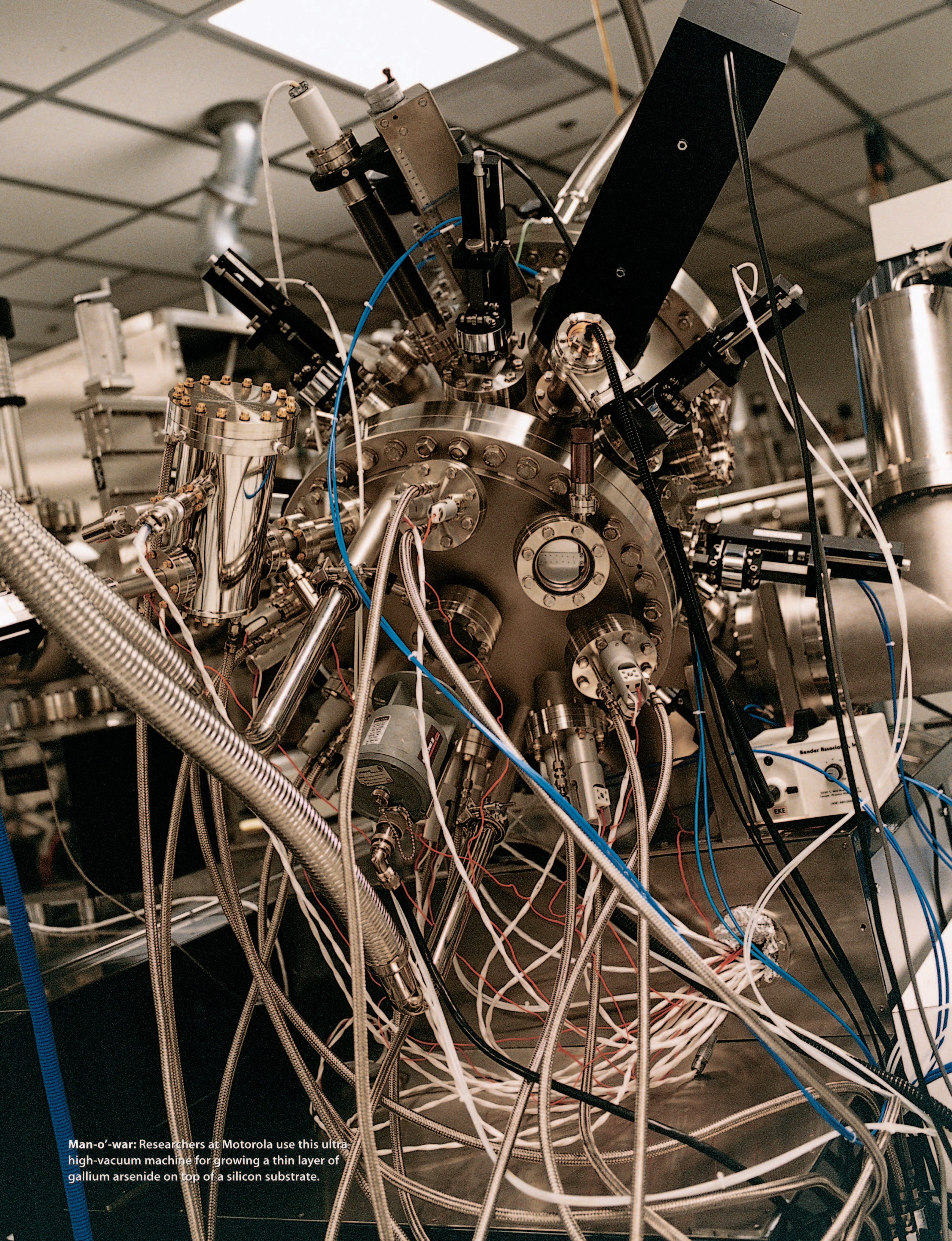
But as transistors get smaller and this layer gets thinner, it becomes more prone to leaking electrons. To solve this problem, Ramdani and his colleagues Ravi Droopad and Jimmy Yu were experimenting with an alternative to silicon dioxide—strontium titanate—that could improve the performance of silicon-based chips. Yet as the Motorola researchers deposited a bee's breath's

Superchip Ingredients



Motorola researchers dream of one day fabricating multipurpose chips (above) with onboard optical and wireless devices made of gallium arsenide, and a microprocessor carved out of the exposed silicon substrate.

The firm hopes to realize that dream with its new technology (left). An internal layer, composed of silicon dioxide and strontium titanate, provides a molecular bridge between the different crystal sizes of silicon and gallium arsenide.



Man-o'-war: Researchers at Motorola use this ultra-high-vacuum machine for growing a thin layer of gallium arsenide on top of a silicon substrate.

worth of strontium titanate on a silicon surface, an intervening layer of silicon dioxide formed. It was like inadvertently covering a window with a layer of black paint when all you wanted to do was slightly tint it.

And then, Ramdani visited that Spanish beach. While relaxing on the sand, he realized that the silicon dioxide layer, along with the strontium titanate, might serve a far larger purpose than he had originally imagined: intermediate layers that, when sandwiched between silicon and gallium arsenide, could reconcile the crystalline mismatch between the two semiconductors. That's because the distances between the atoms in strontium titanate, when on top of the silicon dioxide layer that forms underneath it, are longer than those in silicon but shorter than those in gallium arsenide. In fact, it's the silicon dioxide that causes the atoms in strontium titanate to relax completely and assume a configuration more in line with that of the gallium arsenide atoms above. Within days of returning from his vacation, Ramdani and his team of engineers succeeded in growing gallium arsenide on silicon using these intervening layers *(see "Superchip Ingredients" p. 75)*.

AS RAMDANI AND HIS COLLEAGUES SEE IT, THE SAME TYPE OF INNER LAYER THAT THEY USE TO MARRY GALLIUM ARSENIDE TO SILICON COULD BE USED TO GROW INDIUM PHOSPHIDE OR ANY NUMBER OF OTHER HIGH-PERFORMANCE COMPOUND SEMICONDUCTORS ON THE SAME INEXPENSIVE SILICON SUBSTRATE.

Compounding Interest

As the Motorola researchers refine their technology over the coming years and learn to grow other compound semiconductors on top of silicon, the potential applications of the material ought to continue expanding. As Ramdani and his colleagues see it, the same type of inner layer that they use to marry gallium arsenide to silicon could be used to grow indium phosphide or any number of other high-performance compound semiconductors on the same inexpensive silicon substrate. Each of these compound semiconductors has its own personality—its own speed and light-emitting properties.

Such technology could also lead to new kinds of devices or applications that previously have not been cost effective. Cheap sources of high-performance chips, for example, could make it easier for designers to add wireless communications to household appliances and connect them to the Internet. Visions of washing machines directly communicating with service centers when they go on the fritz or refrigerators that call in food orders to the supermarket could become cheaper to realize, if no more desirable. More affordable light-emitting and light-detecting chips could change the economics of fiber-optic links for directly connecting home computers, video cameras and other domestic gadgetry to the Internet.

Beyond that, chip manufacturers like Motorola and AmberWave Systems share the same longer-term technodream—an all-in-one wafer. In this vision, compound semiconductors are not just layered on top of a silicon substrate, but the different semiconductors are integrated together on the chip. "If we can grow a thin film of gallium arsenide on top of silicon wafers, then maybe we can selectively grow islands of gallium arsenide on silicon," says Charles Huang, cofounder and chief technical officer of Anadigics, a chip manufacturing firm based in Warren, NJ.

Each island would have its own function—say, sending and receiving messages wirelessly, or transmitting data optically to the outside world. Yet the majority of the silicon would be available to do the actual computing or storing of data. Such multitalented chips would, for instance, be able to shuttle data around a microprocessor optically. In a computer, data currently moves electronically both within chips and between chips—between, say, a microprocessor and a memory chip—through tiny wires that slow everything down. "The wires are the real bottleneck in computers," says Ramdani. If each silicon chip came with its own onboard lasers made of compound semiconductors for moving data around, such chips would both operate more quickly on their own and be able to trade larger amounts of data with other chips more quickly.

It's too soon to rule out the possibility that some lurking glitch will send Motorola's growing investment in its new technology into the vast heap of good tries gone bad. Certainly there are a number of skeptics out there still not convinced that the company's superchip will ever live up to its hype. Nevertheless, in the three years since Ramdani's original epiphany, Motorola has increasingly committed itself to making sure the technology fulfills its many promises, throwing its substantial financial and technical weight behind it.

Indeed, Ramdani's excitement over the breakthrough is far from waning. "The way I see it, this technology is going to revolutionize the semiconductor industry," he says. "It will allow us to do things that, 20 years ago, we could only dream of doing." TR

PUMPING UP SILICON

A sample of companies pushing the limits of semiconductor materials

COMPANY	LOCATION	TECHNOLOGY
Thoughtbeam	Austin, TX	Compound semiconductors on silicon
AmberWave Systems	Salem, NH	Strained silicon
IBM Watson Research Center	Yorktown Heights, NY	Strained silicon
Toshiba	Tokyo, Japan	Strained silicon

Q & A

LORD OF THE ROBOTS

PHOTOGRAPHS BY KATHLEEN DOOHER

RODNEY BROOKS, DIRECTOR OF MIT'S ARTIFICIAL INTELLIGENCE LAB, IS HELPING BRING AUTONOMOUS, INTELLIGENT MACHINES INTO EVERYDAY USE.

Proud papa: Rodney Brooks poses with Cog, a humanoid robot in MIT's A.I. lab.

"Computer! Turn on the lights!"

Rodney Brooks, director of MIT's Artificial Intelligence Laboratory—the largest A.I. lab in the world—strides into his ninth-floor office in Cambridge, MA. Despite his demand, the room stays dark. "Computer!" he repeats, sitting down at the conference table.

"*I'm…already…listening,*" comes a HAL-like voice from the wall. Brooks redirects his request toward a small microphone on the table, this time enunciating more clearly: "Turn on the lights!"

A pleasant tweeting sound signals digital comprehension. The lights click on. Brooks grins, his longish, graying curls bouncing on either side of his face, and admits his entrance was a somewhat rough demonstration of "pervasive computing." That's a vision of a post-PC future in which sensors and microprocessors are wired into cars, offices and homes—and carried in shirt pockets—to retrieve information, communicate and do various tasks through speech and gesture interfaces. "My staff laughs at me," says Brooks, noting he could have simply flicked the light switch, "but I have to live with my technology."

In the not-too-distant future, a lot more people may be living with technologies that Brooks's lab is developing. To help make pervasive computing a reality, researchers in his lab and MIT's Laboratory for Computer Science are developing—in an effort Brooks codirects called Project Oxygen—the requisite embeddable and wearable devices, interfaces and communications protocols. Others are building better vision systems that do things like interpret lip movements to increase the accuracy of speech recognition software.

Brooks's A.I. Lab is also a tinkerer's paradise filled with robotic machines ranging from mechanical legs to "humanoids" that use humanlike expressions and gestures as intuitive human-robot interfaces—something Brooks believes will be critical to people accepting robots in their lives. The first generation of relatively mundane versions of these machines is already marching out of the lab. The robotics company Brooks cofounded—Somerville, MA-based iRobot—is one of many companies planning this year to launch new robot products, like autonomous floor cleaners and industrial tools built to take on dirty, dangerous work like inspecting oil wells.

Of course, autonomous oil well inspectors aren't as thrilling as the robotic servants earlier visionaries predicted we'd own by now. But as Brooks points out, robotics and artificial intelligence have indeed worked their way into everyday life, though in less dramatic ways *(see "A.I. Reboots," TR March 2002)*. In conversations with *TR* senior editor David Talbot, Brooks spoke (with occasional interruptions from his omnipresent computer) about what we can expect from robotics, A.I. and the faceless voice from the hidden speaker in his wall.

TR: The military has long been the dominant funder of robotics and A.I. research. How have the September 11 terror attacks influenced these fields?

BROOKS: There was an initial push to get robots out into the field quickly, and this started around 10 a.m. on September 11 when John Blitch [director of robotics technology for the National Institute for Urban Search and Rescue in Santa Barbara, CA] called iRobot, along with other companies, to get robots down to New York City and look for survivors in the rubble. That was just a start of a push to get things into service that were not quite ready—and weren't necessarily meant for particular jobs. In general, there has been an urgency to getting things from a development stage into a deployed stage much more quickly than was assumed would be necessary before September 11. I think people saw there was a real role for robots to keep people out of harm's way.

TR: What else besides…

COMPUTER: *I'm…already…listening.*

BROOKS: Go to sleep. Go to sleep. Go…to…sleep.

COMPUTER: *Going…to…sleep.*

BROOKS: As long as we don't say the "C" word now, we'll be okay.

TR: Did any other robots get called for active duty?

BROOKS: Things that were in late research-and-development stages have been pushed through, like iRobot's "Packbot" robots. These are robots that a soldier can carry and deploy. They roll on tracks through mud and water and send back video and other sensory information from remote locations without a soldier going into the line of fire. They can go into rubble; they can go where there are booby traps. Packbots were sent for search duty at the World Trade Center site and are moving into large-scale military deployment more quickly than expected. There is more pressure on developing mine-finding robots.

TR: How are you balancing military and commercial robot research?

BROOKS: When I became A.I. Lab director four and a half years ago, the Department of Defense was providing 95 percent of our research funding. I thought that was just too much, from any perspective. Now it's at about 65 percent, with more corporate funding.

TR: What's the future of commercial robots?

BROOKS: There has been a great deal of movement toward commercial robots. Last November, Electrolux started selling home-cleaning robots in Sweden. They have a plan to sell them under the Eureka brand in the U.S. There are a bunch of companies that plan to bring out home-cleaning robots later this year, including Dyson in the U.K., Kärcher in Germany and Procter and Gamble in the U.S. Another growing area is remote-presence robots; these are being investigated more closely, for example, to perform remote inspections above ground at oil drilling sites. Many companies are starting to invest in that area. IRobot just completed three years of testing on oil well robots that actually go underground; we're now starting to manufacture the first batch of these.

TR: How is that different from other industrial robots, like spot welders, that have been around for years?

BROOKS: These robots act entirely autonomously. It's impossible to communicate via radio with an underground robot, and extreme depths make even a lightweight fiber-optic tether impractical. If they get in trouble they need to reconfigure themselves and get back to the surface. They have a level of autonomy and intelligence not even matched by the Mars rover Sojourner, which could get instructions from Earth. You don't need a crew of workers with tons of cable or tons of piping for underground inspections and maintenance. You take this robot—which weighs a few hundred pounds—program it with instructions, and it crawls down the well. You have bunches of sensors on there to find out flow rates, pressures, water levels, all sorts of things that tell you the health of the well and what to do to increase oil production. They will eventually open and close sleeves that let fluids feed into the main well pipe and make adjustments. But the first versions we're selling this year will just do data collection.

TR: The computer that turned on the lights is part of MIT's Project Oxygen, which aims to enable a world of pervasive computing. As codirector, what are your objectives?

BROOKS: With Project Oxygen, we're mostly concentrating on getting pervasive computing working in an office environment. But the different companies investing in Project Oxygen obviously have different takes on it. Philips is much more interested in technologies to make information services more available within the home. Delta Electronics is interested in the future of large-screen displays—things that can be done if you have wall-sized displays you can sell to homeowners. Nokia is interested in selling information services. They call a cell phone a "terminal." They want to deliver stuff to this terminal and find ways we can interact with this terminal. Already, Nokia has a service in Finland where you point the cell phone at a soda machine and it bills you for the soda. In Japan, 30 million people already browse the Web on their cell phones through NTT's i-mode. All these technologies are providing services from computing in everyday environments. We are trying to identify the next things, to see how we can improve upon or go beyond what these companies are doing.

TR: To that end, Project Oxygen is developing a handheld device called an "H21" and an embedded-sensor suite called an "E21." But what, exactly, will we do with these tools—besides turn on the lights?

BROOKS: The idea is that we should have all our information services always available, no matter what we are doing, and as unobtrusive as possible. If I pick up your cell phone today and make a call, it charges you, not me. With our prototype H21s, when you pick one up and use it, it recognizes your face and customizes itself to you—it knows your schedule and where you want to be. You can talk to it, ask it for directions or make calls from it. It provides you access to the Web under voice or stylus command. And it can answer your questions rather than just giving you Web pages that you have to crawl through.

The E21s provide the same sorts of services in a pervasive environment. The walls become screens, and the system handles multiple people by tracking them and responding to each person individually. We are experimenting with new sorts of user interfaces much like current whiteboards, except with software systems understanding what you are saying to other people, what you are sketching or writing, and connecting you with, for instance, a mechanical-design system as you work. Instead of you being drawn solitarily into the computer's virtual desktop as you work, it supports you as you work with other people in a more natural way.

TR: How common will pervasive computing become in the next five years to 10 years?

BROOKS: First we have to overcome a major challenge—making these devices work anywhere. As you move around, your wireless environment changes drastically. There are campuswide networks, and cell phones in different places with

different protocols. You want those protocols to change seamlessly. You want to have these handheld devices work independent of the service providers. Hari Balakrishnan [an assistant professor at MIT's Laboratory for Computer Science] and students have demonstrated the capability—which has had great interest from the corporate partners—in having a totally roaming Internet, which we don't have right now. That's something I expect will be out there commercially in five years.

TR: And in 10 years?
BROOKS: In 10 years, we'll see better vision systems in handheld units and in the wall units. This will be coupled with much better speech interfaces. In 10 years the commercial systems will be using computer vision to look at your face as you're talking to improve recognition of what you are saying. In a few years, the cameras, the microphone arrays will be in the ceiling in your office and will be tracking people and discriminating who is speaking when, so that the office can understand who wants to do what and provide them with the appropriate information. We're already demonstrating that in our Intelligent Room here in the A.I. Lab. I'll be talking to you—then I'll point, and up on the wall comes a Web page that relates to what I'm saying. It's like *Star Trek*, in that the computer will always be available.

TR: What is the state of A.I. research?
BROOKS: There's this stupid myth out there that A.I. has failed, but A.I. is everywhere around you every second of the day. People just don't notice it. You've got A.I. systems in cars, tuning the parameters of the fuel injection systems. When you land in an airplane, your gate gets chosen by an A.I. scheduling system. Every time you use a piece of Microsoft software, you've got an A.I. system trying to figure out what you're doing, like writing a letter, and it does a pretty damned good job. Every time you see a movie with computer-generated characters, they're all little A.I. characters behaving as a group. Every time you play a video game, you're playing against an A.I. system.

TR: But a robotic lawn mower still can't be relied upon to cut the grass as well as a person. What are the major problems that still need solving?
BROOKS: Perception is still difficult. Indoors, cleaning robots can estimate where they are and which part of the floor they're cleaning, but they still can't do it as well as a person can do. Outdoors, where the ground isn't flat and landmarks aren't reliable, they can't do it. Vision systems have gotten very good at detecting motion, tracking things and even picking out faces from other objects. But there's no artificial-vision system that can say, "Oh, that's a cell phone, that's a small clock and that's a piece of sushi." We still don't have general "object recognition." Not only don't we have it solved—I don't think anyone has a clue. I don't think you can even get funding to work on that, because it is just so far off. It's waiting for an Einstein—or three—to come along with a different way of thinking about the problem. But meantime, there are a lot of robots that can do without it. The trick is finding places where robots can be useful, like oil wells, without being able to do visual object recognition.

TR: Your new book *Flesh and Machines: How Robots Will Change Us* argues that the distinctions between man and machine will be irrelevant some day. What does that mean?
BROOKS: Technologies are being developed that interface our nervous systems directly to silicon. For example, tens of thousands of people have cochlear implants where electrical signals stimulate neurons so they can hear again. Researchers at the A.I. Lab are experimenting with direct interfacing to nervous systems to build better prosthetic legs and bypass diseased parts of the brain. Over the next 30 years or so we are going to put more and more robotic technology into our bodies. We'll start to merge with the silicon and steel of our robots. We'll also start to build robots using biological materials. The material of us and the material of our robots will converge to be one and the same, and the sacred boundaries of our bodies will be breached. This is the crux of my argument.

TR: What are some of the wilder long-term ideas your lab is working on or that you've been thinking about?
BROOKS: Really long term—really way out—we'd like to hijack biology to build machines. We've got a project here where Tom Knight [senior research scientist at the A.I. Lab] and his students have engineered E. coli bacteria to do very simple computations and produce different proteins as a result. I think the really interesting stuff is a lot further down the line, where we'd have digital control over what is going on inside cells, so that they, as a group, can do different things. To give a theoretical example: 30 years from now, instead of growing a tree, cutting it down and building a table, we'd just grow a table. We'd change our industrial infrastructure so we can grow things instead of building them. We're a long way away from this. But it would be almost like a free lunch. You feed them sugar and get them to do something useful!

TR: Project Oxygen. Robots. Growing tables. What's the common intellectual theme for you?
BROOKS: It all started when I was 10 years old and built my first computer, in the early 1960s. I would switch it on and the lights flashed and it did stuff. That's the common thread—the excitement of building something new that is able to do something that normally requires a creature, an intelligence of some level.

TR: That excitement is still there?
BROOKS: Oh yeah.

THERE'S THIS STUPID MYTH OUT THERE THAT A.I. HAS FAILED. BUT A.I. IS EVERYWHERE, TUNING THE FUEL INJECTOR IN YOUR CAR, CHOOSING YOUR GATE AT THE AIRPORT AND COMPETING AGAINST YOU IN VIDEO GAMES.

NEW O.J. TRIAL: RECIPE FOR DISASTER

Talk about hoarding the fruits of innovation! Talk about a juicy patent dispute! I know I should be chronicling cutting-edge fights over rights to nanotech devices, genomic tags or esoteric new software applications. But let's face it: an all high-tech diet can be hard to swallow. So on today's menu I'm serving up nothing but 100 percent pure, premium, not-from-concentrate Florida orange juice.

You see, something's gone sour in the orange grove. In an all-too-common tactic, Tropicana, a division of PepsiCo, is abusing the U.S. patent system to—please excuse the pun—put the squeeze on its competitors. And I'm convinced the case offers an important cautionary tale about innovation today.

People have been growing citrus in Florida's sun-drenched groves for a very long time, putting a lot of effort into caring for the trees and figuring out the most efficient ways to harvest the fruit. But making orange juice remains a fabulously straightforward process: you pick the ripest oranges you can and press the juice from them, just the way nature made it, adding nothing.

Here's what's happening: Valencias are the oranges of choice for the popular "not-from-concentrate" juice—the refrigerated stuff that comes ready to drink in cartons or plastic jugs. But Valencias are a late-season variety. So growers have put a lot of time and money into developing earlier-ripening varieties that can match Valencias' sweetness and rich color. Much of this grower-funded research has been done over the past decade at the Citrus Research and Education Center at the University of Florida.

But now, Tropicana has found a way to get a proprietary lock on this research. Believe it or not, U.S. patent 6,143,347 grants the firm the exclusive right to blend its juice from certain particularly desirable early-season oranges, including varieties called Earlygold, Ruby, Itaborai and Westin. Tropicana was already the biggest purchaser of these orange varieties. Now, as a practical matter, its patent guarantees it a monopoly by legally preventing other orange juice processors from buying these varieties to make any blend of not-from-concentrate juice.

Why would the U.S. Patent Office hand out a 20-year monopoly on something like this? I think it is because the good people there have lost track of what an invention is. By no stretch of the imagination has Tropicana patented an invention. It has patented a recipe. And it is a recipe for disaster with implications far beyond the breakfast table.

The difference is subtle but tremendously important. To be eligible for a patent, an invention may draw upon existing materials, so long as it combines them in a novel and *useful* way. If I came up with a blend of orange juices that could cure cancer, now that would be a novel use worthy of patent protection. But Tropicana makes no such claims. On the contrary, what distinguishes most recipes is that they yield nothing unexpected beyond the combination of their ingredients. Your juice blend might taste better than mine, but that's not enough to be considered a useful new invention. That's why, historically, recipes have not been able to surmount the U.S. Patent Office's sensible "usefulness" hurdle—and they shouldn't be.

Put another way, the patent system is a contract between inventors and society. It only makes sense for the government to grant a time-limited monopoly in exchange for the added social value that a novel and useful invention brings when it comes to the marketplace. Along these lines, bona fide inventions certainly deserve patents. But Uncle Sam should leave it to the market to determine whose recipes are the most valuable.

Can the U.S. Patent Office tell the difference between a recipe and an invention? Not if Tropicana's monopoly on blending early-season orange varieties is any guide.

Tropicana spokeswoman Kristine Nickel, not surprisingly, claims that Tropicana's orange juice patent is "in the true spirit of what patents are for." As she puts it, "For us it's not about restricting the market. It's about protecting the investment that we made in the research for these varieties of juice."

But the fact is, Tropicana doesn't even claim to have developed the orange varieties.

The people at Florida Citrus Mutual, a Lakeland-based grower trade association with nearly 12,000 members, are furious enough about the situation that they're legally challenging Tropicana—one of their largest customers—to try to get the patent invalidated. As Andy LaVigne, Florida Citrus Mutual's executive vice president, explains, the varieties used in Tropicana's recipe were largely developed by funds from growers, and the advantages of blending juices have been well known in the Florida citrus industry for as long as anyone can remember. "There is nothing about the characteristics of the varieties or the blending of the juices that is new or novel; therefore the patent should be declared invalid," LaVigne charges.

The patent office is due to rule on the case soon. Now, if it can just reestablish the difference between a recipe and an invention, I'll be sure to raise my juice glass in tribute. TR

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VISUALIZE

HOW TECHNOLOGY WORKS

By Tracy Staedter | Illustration by John MacNeill

HAPTICS

A glove and mechanical assembly let you feel the unreal

Most virtual-reality systems immerse you in a world of virtual sight, sound and motion. But even these sensory-laden experiences can seem like glorified spectating. If you really want to participate, you need the sense of touch.

Few computer-simulated environments offer haptic (from the Greek *haptikos*, meaning "to touch") interfaces that do more than buzz or vibrate. Building the devices and writing the programs to control them have been costly endeavors. Touch-technology developer Immersion in San Jose, CA, is among a handful of companies offering commercial products, such as CyberGrasp, that let users press, push, pull, punch, squeeze, swat and sculpt virtual objects in a computer-generated world.

CyberGrasp consists of a lightweight mechanical assembly, or exoskeleton, that fits over a motion capture glove. About 20 flexible semiconductor sensors sewn into the fabric of the glove measure hand, wrist and finger movement. The sensors send their readings to a computer that displays a virtual hand mimicking the real hand's flexes, tilts, dips, waves and swivels.

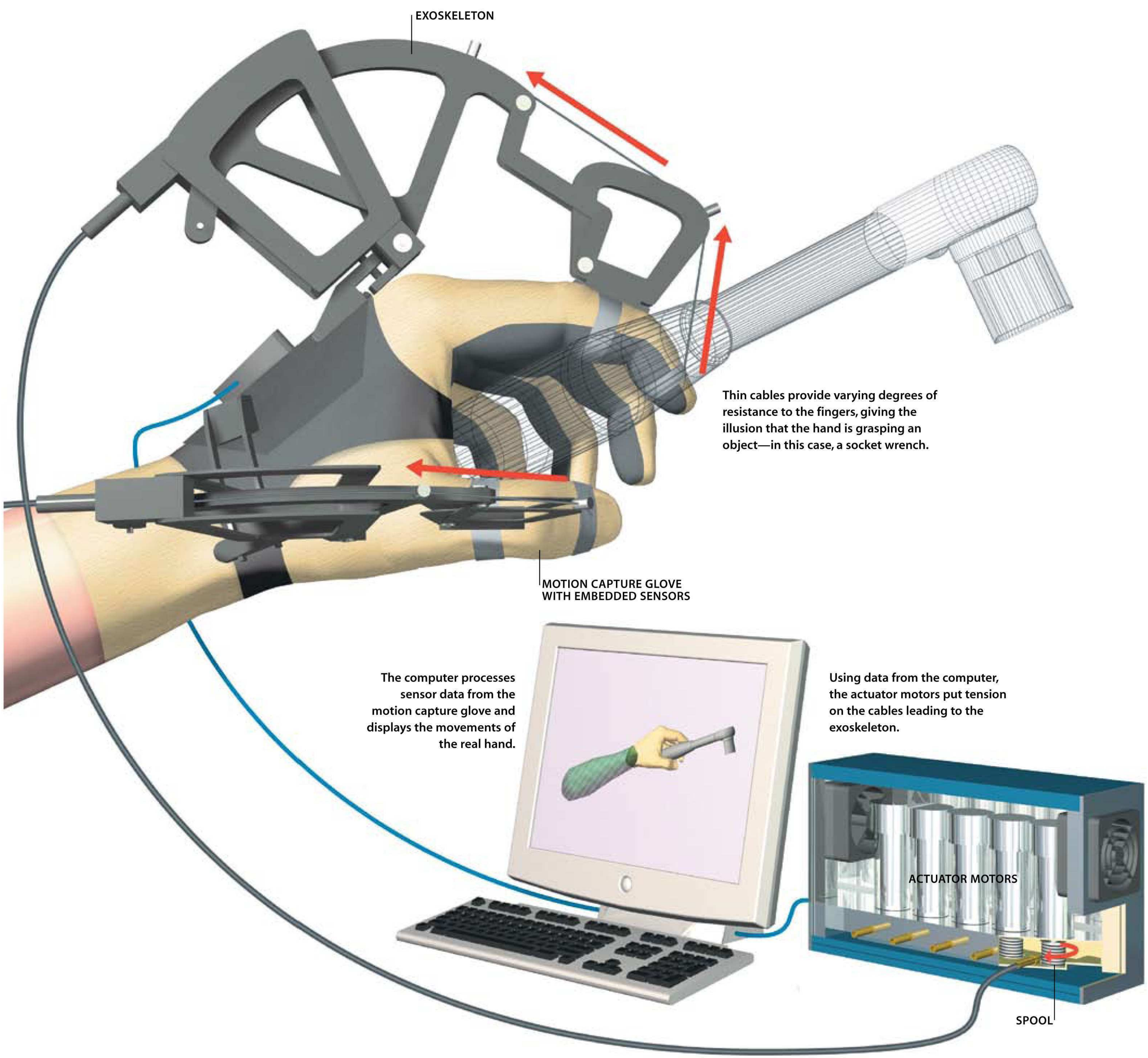
The same program that moves the virtual hand on the screen also directs machinery that exerts palpable forces on the real hand, creating the illusion of touching and grasping. A special computer called a force control unit calculates how much the exoskeleton assembly should resist movement of the real hand in order to simulate the on-screen action. Each of five actuator motors turns a spool that rolls or unrolls a cable. The cable conveys the resulting pushes or pulls to a finger via the exoskeleton. If the virtual hand is grasping a virtual wrench, for example, the actuators provide resistance to the human fingers at the points where they would touch the tool's edges.

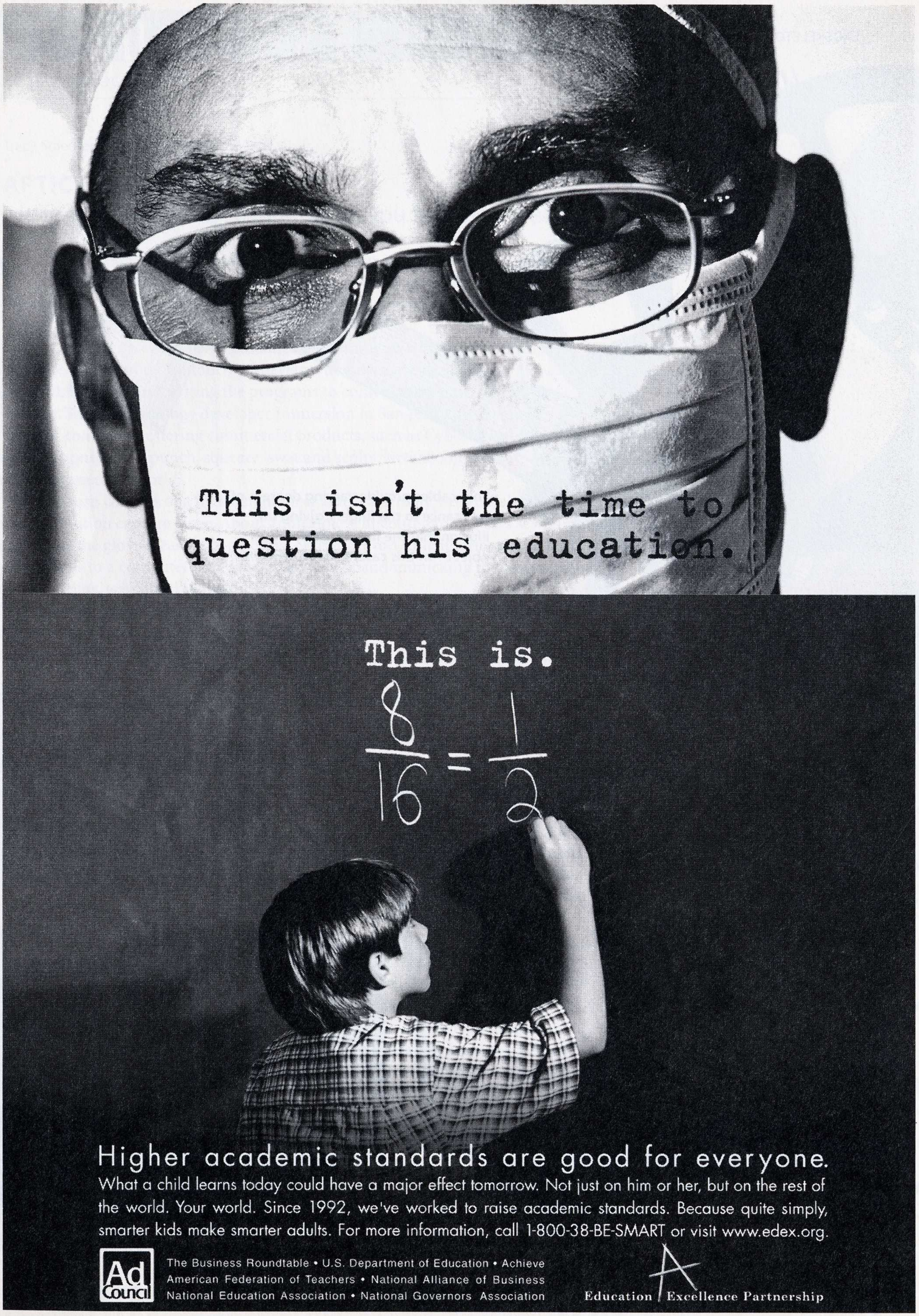
DAVE LEPORI

The CyberGrasp is not alone in the feel-good market. Woburn, MA-based SensAble Technologies, founded by MIT haptics pioneer Thomas H. Massie, makes several touch-based modeling systems for industrial designers. SensAble's FreeForm system consists of a stylus attached to a jointed arm. Actuators exert pressure on the stylus as the user sculpts objects from virtual clay.

Though available now, these technologies cost tens of thousands of dollars. It could be years before you find yourself feeling your way through the virtual world. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize

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CYBERSPACE AND RACE

"In Cyberspace, nobody knows your race unless you tell them. Do you tell?" Several years ago, I put this slogan on a poster advertising an MIT-hosted public forum about race and digital space. The resulting controversy was an eyeopener.

Like many white liberals, I had viewed the absence of explicit racial markers in cyberspace with some optimism—seeing the emerging "virtual communities" as perhaps our best hope ever of achieving a truly color-blind society.

But many of the forum's minority participants—both panelists and audience members—didn't experience cyberspace as a place where nobody cared about race. Often, they'd found that people simply assumed all participants in an online discussion were white unless they identified themselves otherwise. One Asian American talked of having a white online acquaintance e-mail him a racist joke, which he would never have sent if he had known the recipient's race. Perhaps covering up for his own embarrassment, the white acquaintance had accused the Asian-American man of "trying to pass as white."

Even when more than one minority was present in a chat room, the forum participants said, they didn't recognize each other as such, leaving each feeling stranded in a segregated neighborhood. If they sought to correct ignorant misperceptions in online discussions, they were accused of "bringing race into the conversation." Such missteps were usually not the product of overt racism. Rather, they reflected the white participants' obliviousness about operating in a multiracial context.

Perhaps when early white Netizens were arguing that cyberspace was "color-blind," what they really meant was that they desperately wanted a place where they didn't have to think about, look at or talk about racial differences. Unfortunately, none of us knows how to live in a race-free society. As Harvard University law professor Lani Guinier explains, "We don't live next door to each other. We don't go to school together. We don't even watch the same television shows." Computers may break down some of the hold of traditional geography on patterns of communication, but we won't overcome that history of segregation by simply wishing it away. And as the Web culture becomes more globalized, it will only get more complicated.

So far, these topics have entered the national conversation through talk about the so-called digital divide, the gap between white and minority, rich and poor, in computer access and use. Such talk often assumes that if we combat the technological and economic problems of access, cyberspace will become more democratic. I do hope governmental and corporate resources are brought to bear on the problem, but equal access is not the same as equal participation. Giving everybody broadband is a problem of a very different order than broadening our minds.

When art museums lower economic barriers, offering free or reduced admission, they still attract mostly white upper-middle-class patrons; many lower-income and minority citizens don't feel entitled to attend. Where museums have successfully diversified their communities, it has been through educational outreach and collaboration with minority communities. Efforts to bridge the digital divide must internalize these lessons.

Some have argued that class, rather than race, may be the strongest indicator of who has access—though we need to recognize that in a society where the average black family income is roughly half that of the average white family income, race and class are not easily separable. It is hard to imagine universal computer literacy in a country that has yet to ensure that all citizens can read and write—and again, there is a strong correlation between race, class and literacy rates.

There are some hopeful signs that racially based gaps in access are closing: for example, Hispanic Americans are the fastest-growing population online. As minority groups have developed more economic clout, cyberspace has started to seem less racially segregated. Yet this may only take us so far. Bridging the digital divide needs to mean more than allowing corporations access to new markets; it needs to include empowering minority citizens to participate in online policy debates.

People talk about bridging the digital divide by making technology more accessible to all, but giving everybody broadband is a problem of a very different order than broadening our minds.

Most digital-divide rhetoric depicts a world where undereducated, undermotivated and underemployed minorities are competing against technologically sophisticated whites. Many scholars and activists contend that such talk may intensify the cultural barriers to full participation and thus become a self-fulfilling prophecy. They argue that we need to be focusing on success stories, examining those projects—whether activist, entrepreneurial or educational in origin—that have significantly increased access, visibility and participation within minority communities. Our children need to know about the ways that minorities have been technological innovators rather than seeing them as constantly lagging behind.

In the end, we will need to give up any lingering fantasies of a color-blind Web and focus on building a space where we recognize, discuss and celebrate racial and cultural diversity. To achieve that goal, all of us—white folks and people of color—will have to shed the defensiveness that surrounds the topic of race. Many are experimenting with new ground rules and modes of communication that enable us to explore the potential of digital technology to bring together people who would historically have never had contact and encourage them to compare notes, test assumptions and overcome ignorance and stereotyping. Out of such conversations might come practical approaches for combating racism, not only online, but off.

ELIMINATING THE TOOLS OF TERROR

It's time for new technologies that civilians can use but terrorists can't. BY GREG BLONDER

How can we stop bank robbers in their tracks? A politician might suggest doubling the number of guards to calm the public and intimidate would-be thieves. A policeman might recommend installing more video cameras, combination locks and metal gates. A judge might advocate increasing legal penalties for armed robbery.

These approaches, though well meaning, would remain tedious, expensive and arbitrary; no matter how great our resolve, we simply can't anticipate every threat to every bank in the country. Fortunately, there is another solution, inspired by Willie Sutton's purported explanation of why he robbed banks: "Because that's where the money is." If banks no longer distributed hard currency and became mere financial-service centers—turning over the payment function to smart debit cards—bank robberies would stop.

So far, society prefers to absorb the cost of bank robberies rather than move to a cash-free economy. Yet Sutton's practical observation offers an important clue to addressing a challenge that our society does judge intolerable: terrorism. The most effective way to address terrorism is neither better offense nor better defense. Rather, it is to *take away the ball*. Creatively eliminate the tools of terrorism, and you go a long way toward eliminating the terrorist.

How do we, for example, stop airplanes from doubling as aerial suicide bombs? Answer: sponsor more research on fuel additives that prevent jet fuel from catching fire outside an engine. NASA, among other groups, has investigated such "fuel-inerting" and "antimisting" technologies, but progress to date is modest due to inadequate funding and industry support.

How do we stop fertilizer from doubling as a bomb-making ingredient, as it did in Oklahoma City? Eliminate the need for conventional fertilizer by developing crops capable of fixing nitrogen from the air. Plants such as soybeans have evolved bacteria-filled nitrogen-fixing nodules in their roots. Genetic engineering and conventional plant breeding techniques could transfer this important characteristic to other crops.

How do we keep our water supply safe from bioterrorists? A water purifier in every building and every home. New technologies combining ozone, ultraviolet radiation and mechanical and carbon filtration can eliminate every possible impurity, from volatile organic chemicals to viruses.

Such approaches not only make tactical sense, they make strong economic sense as well. Fuels that fail to catch fire outside an engine would reduce the fatality rates and material costs of all air and auto accidents. New nitrogen-fixing crops would reduce the amount of energy required to manufacture petroleum-based fertilizers and ship them to the farm. They would also reduce our dependence on foreign oil, while helping spread peace and stability by lowering the cost of large-scale agriculture in developing countries. More

JAMES STEINBERG

effective technologies for on-location water purification could lower the cost of recycling suburban "gray" waste water and provide an inexpensive source of potable water for many of the world's poor.

None of this activity would, of course, do much to lessen the short-term hit to our economy from the September 11 attacks. According to the National Governors' Association and other agencies, the antiterrorist campaign's first year alone will drain tens of billions from the already faltering U.S. economy. Every dollar spent fighting this war is a stunning blow to world productivity and could well be echoed in higher inflation rates, followed by a lowered standard of living. The events of September 11 were, indeed, attacks on a way of life, and their effectiveness must be judged in terms of not only lost lives, but also lost livelihoods.

We must also begin to think creatively, therefore, about ways to prevent this short-term cycle from turning into a longer-term spiral. The war on our current terrorist enemies could stretch indefinitely into the future. Moreover, new enemies, aware as never before of our society's vulnerabilities, may well attempt to exploit them in the years ahead. That is where a coordinated campaign to combine terrorism prevention with economic growth becomes crucial.

Dual-use technologies boost the economy by meeting both military and civilian needs. But now we need more: "deny-use" technologies that can't be turned against us.

We have ample precedent for such a campaign. In the last 20 years, the U.S. government has come to recognize that many military technologies are too expensive to build independently and are best developed in tandem with civilian applications. Often called "dual-use" technologies, they have included the integrated circuit, which was first used for military applications such as Minuteman missile guidance and now powers everything from kids' video games to supercomputers to military situation rooms. Reliable civilian golf carts, to cite another example, carry landscapers around parks in the United States; yet slightly repurposed, they serve as low-cost battlefield ambulances in Afghanistan.

Dual-use technologies offer dual economies in the war on terrorism. They reduce costs by increasing production volume. But just as important, they expand the base of designers, testers and users, thus greatly expanding the number of smart people evaluating and improving them. Cheaper products and more brainpower—a powerful one-two punch!

Yet the dual-use doctrine alone doesn't give us sufficient leverage to defeat terrorism. The problem is that many dual military-civilian technologies can still be misused or circumvented. To return to the bank heist comparison: banks that adopt consumer video cameras for surveillance or use radio-controlled model airplanes to track getaway cars could still be robbed and innocent bystanders killed. As Sutton said, it's not the bank, it's the money. Less-flammable fuels and nitrogen-fixing plants are therefore more accurately described as "deny-use" technologies—the next step in the evolution of dual use.

Taken to its logical conclusion, deny-use should extend to our weapons systems themselves. A common scenario for a terrorist attack, for example, involves the firing of a shoulder-launched Stinger missile against Air Force One or the Capitol. Our ability to stop this kind of attack is very limited, depending almost entirely on intervention through counterintelligence methods.

Yet think for a moment about how terrorists acquire those weapons. The United States produces them and gives them to friendly powers. As the years pass, they often find their way into unfriendly hands. How can the deny-use doctrine neutralize this threat? To give just one example, we could design our weapons to degrade, so that after three to five years the Stinger's rocket fuel and explosives would be inoperable.

Degradable weaponry offers other potential advantages as well. Short-lived mines, for example, would pose a far smaller threat to farmers and other civilians than the millions of unexploded mines that lurk under yesterday's battlefields. And from a business standpoint, degradable weapons could be part of a military-commercial partnership focused on "design-for-recycling" techniques much like the ones now used by the European auto industry. Saving lives, saving money and saving the environment in one program—now that's the American way.

In the coming R&D war on terrorism, Congress, the U.S. Defense Advanced Research Projects Agency and other organizations should give full attention to promoting antiterrorist technologies that follow two fundamental guidelines. First, these technologies should be designed to deny terrorists tools and targets. Second, they should not be an economic burden on society; they must have a broad and substantial impact on commerce and productivity.

We will never track down every terrorist in the world, nor stop the insane and malevolent from imposing their warped visions on others. But we can deny them targets worthy of attack—including our underlying economic prosperity. TR

Greg Blonder, a general partner at Morgenthaler, a venture capital firm, is a former vice president of research at Bell Labs.

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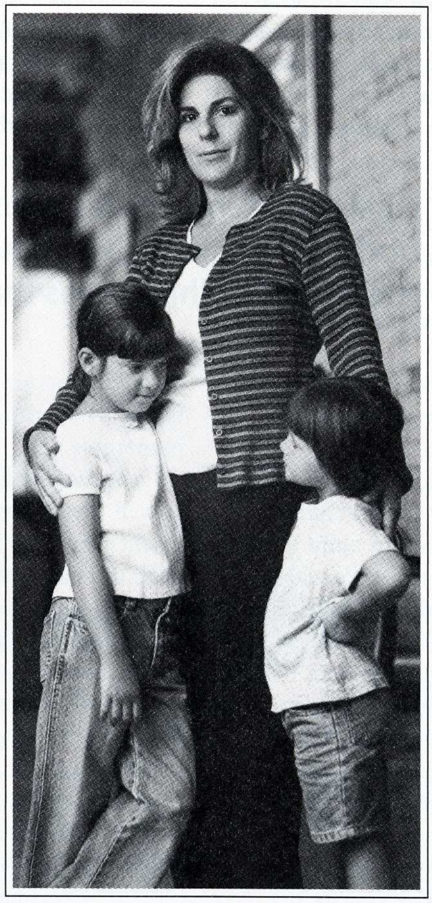
Reading is a great way to escape. It helped this family get out of the projects.



To families living in poverty, it sometimes seems there's no way out. And for many of them, poor literacy skills are the source of their own captivity. Today, one in every five people in America would have difficulty understanding these very words. A parent who can't read a job application can't earn a living. A child who fails in school doesn't earn a diploma. Entire generations become trapped in a bleak pattern of underachievement and need. Their only escape is through the classroom door. 📖 The National Center for Family Literacy is working to help break the cycle of intergenerational poverty by teaching parents and their children the skills necessary for success. Family members learn to read and write well, to maintain good study habits, to hold a steady job. They learn how to manage a household budget and to plan for the future. We hold out a hand and they learn to pull themselves up. 📖 We need a hand as well. You can volunteer to participate in a family literacy program. You can offer someone a job. Or you can simply write out a check. Whatever choice you make, you can be the reason one more family succeeds and poverty fails. 📖 Please call the Family Literacy InfoLine at 1-877-FAMLIT-1 or visit www.famlit.org.

NATIONAL CENTER *for* FAMILY LITERACY

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PEOPLE AND ORGANIZATIONS MENTIONED IN THIS ISSUE

PEOPLE

ORGANIZATIONS

CALL FOR NOMINATIONS

ROBERT A. MUH ALUMNI AWARD IN THE HUMANITIES, ARTS, AND SOCIAL SCIENCES

We invite nominations for the Robert A. Muh Award in the School of Humanities, Arts, and Social Sciences (SHASS). The award will honor in 2003 an MIT alumnus/alumna who has made a significant contribution to education, scholarship and/or academic administration in the Social Sciences. The Robert A. Muh Award was established in 2000 on the 50th anniversary of the School of Humanities, Arts, and Social Sciences to honor an MIT graduate for noteworthy contributions to education, scholarship, or performance, academic administration or arts management in the humanities, arts or social sciences. The award rotates among the three major learning areas in SHASS. The Muh Award comes with a $5,000 honorarium and will require the recipient to deliver a public lecture at MIT at the time of the award's presentation.

Letters of nomination, including a letter in support of the nominee and the nominee's curriculum vitae or résumé, should be sent to:

The Muh Award Selection Committee
MIT, School of Humanities, Arts, and Social Sciences
Building E51-255
77 Massachusetts Avenue
Cambridge, MA 02139-4307
or email: rmalouf@mit.edu

The deadline for nominations is **June 1, 2002.**
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Lighting Technology Breakthrough

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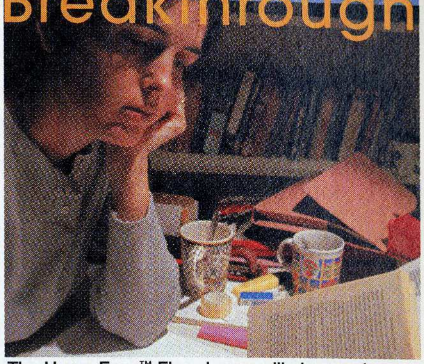

The HappyEyes™ Floor Lamp will change the way you see and feel about your living or work spaces.

Ever since the first human went into a dark cave and built a fire, people have realized the importance of proper indoor lighting. Unfortunately, since Edison invented the light bulb, lighting technology has remained relatively prehistoric. Modern light fixtures do little to combat many symptoms of improper lighting, such as eye strain, dryness or burning. As more and more of us spend longer hours in front of a computer monitor, the results are compounded. And the effects of indoor lighting are not necessarily limited to physical well being. Many people believe that the quantity and quality of light can play a part in one's mood and work performance. Now Verilux®, a leader in healthy lighting since 1956 has developed a better way to bring the positive benefits of natural sunlight indoors.

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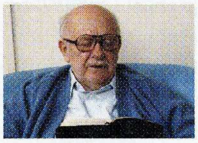
...for hobbies...



...for reading...

...for working...

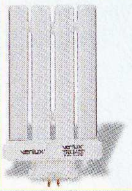
...and when you need a good source of light for close-up tasks.

The HappyEyes™ Floor Lamp will change the way you see and feel about your living or work spaces. Studies show that sunshine can lift your mood and your energy levels, but as we all know the sun, unfortunately, does not always shine. So to bring the benefits of natural daylight indoors, Verilux, The Healthy Lighting Company™, created the HappyEyes Floor Lamp that simulates the balanced spectrum of daylight. You will see with more comfort and ease as this lamp provides sharp visibility for close tasks and reduces eyestrain.

You don't need the Sun to get the natural benefits of daylight

- Replicates the balanced spectrum of natural sunlight
- See with comfort and ease
- Creates natural, glare-free light
- Provides sharp visibility
- Uplifting, cheerful and bright
- Flexible gooseneck design
- Instant-on, flicker-free light

Technology revolutionizes the light bulb



- 5,000 hours bulb life
- Energy efficient
- Shows true colors
- Two light levels

Its 27-Watt compact fluorescent bulb is the equivalent to a 150-Watt ordinary light bulb. This makes it perfect for activities such as reading, writing, sewing and needlepoint, and especially for aging eyes. For artists, the HappyEyes Floor Lamp can bring a source of natural light into a studio, and show the true colors of a work. This lamp has a flexible gooseneck design for maximum efficiency and two levels of light, with an "Instant On" switch that is flicker-free. The high fidelity electronics, ergonomically correct design, and bulb that lasts five times longer than an ordinary bulb makes this product a must-see.

"This light can change the way you live and work

I love it! Reading is so much easier on my eyes. It's also great for doing crafts. The lamp's light weight allows me to bring it anywhere.
—Karen R. CA

It really brightens up my office, Thank you.
—Jan L. GA

I use my computer all the time and WOW what a difference. I just put it up and I can see!
—Kathy N. CA

It is really nice and eliminates the glare!
—Nita P. CA

It is a nice sunny product for a windowless office.
—Edith L. NJ"

Dozens of testimonials on file
Results not typical

Try this risk-free, manufacturer direct special offer. The HappyEyes Floor Lamp comes with a one-year manufacturer's limited warranty and TechnoScout's exclusive risk-free home trial. If you're not fully satisfied, return it within 30 days for a complete "No Questions Asked" refund.

HappyEyes™ Floor Lamp
ZZ-1777......... **$129.95** $15.95 S&H
Please mention source code 21777

For fastest service, call toll-free 24 hours a day

800-399-7853

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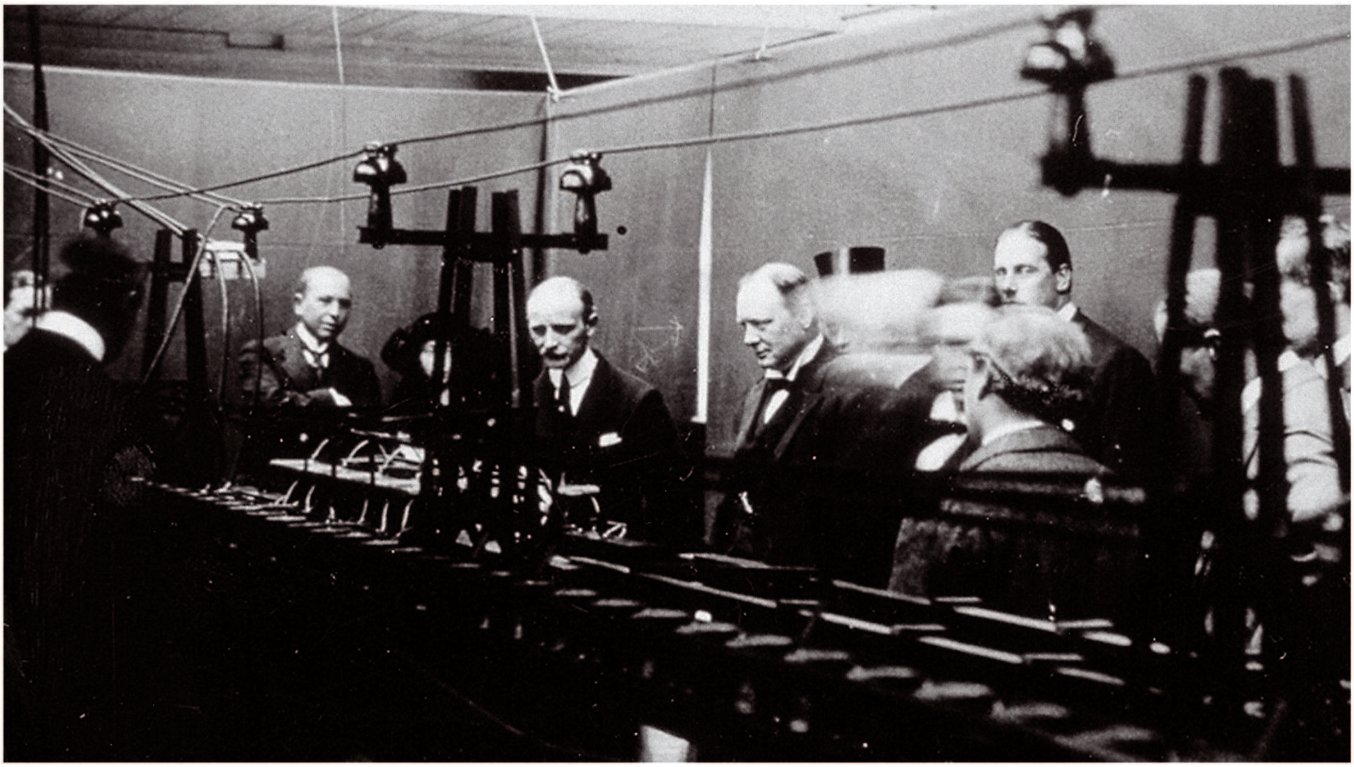

WESTCHESTER COUNTY HISTORICAL SOCIETY

THE MAGLEV MAN

A forgotten inventor's innovation may yet revolutionize transportation

The U.S. Department of Transportation is planning to fund a $950 million magnetically levitated, or "maglev," train project by 2004, and similar trains are currently under development in China and Japan. Maglev technology, which uses the attracting and repelling forces of superconducting magnets to levitate and propel trains at speeds of up to 550 kilometers per hour, is clearly on the move. But the man who designed the first maglev train died long before his dream started to become reality.

French émigré Emile Bachelet was an electrician who patented several therapeutic electromagnetic devices. A brief involvement with a vaudeville magic act, in which he levitated objects with magnets, led to his idea for a magnetically levitated vehicle. He created a fully functional miniature prototype by 1910, about the size of a large toy train, which levitated and moved forward on rails by means of an alternating-current repulsion system using iron core magnets. He received a U.S. patent for his "levitating transmitting apparatus" in 1912.

But to get the train off the ground financially, Bachelet needed an outside investor. The multimillionaire John Jacob Astor IV was intrigued and promised to finance Bachelet upon his return from a European trip. Astor's return, unfortunately, was on *HMS Titanic.*

Bachelet persevered and, by 1914, with the support of British investors, began to give demonstrations of the so-called flying-train model at his London laboratory to deep-pocketed railroad executives and powerful government figures, including then first lord of the admiralty Winston Churchill *(above)*. It seemed things were looking up for Bachelet—but then World War I broke out, and interest in his train collapsed.

In addition to bad luck, one key practical problem with the technology continued to plague Bachelet: the amount of electrical power required to run a full-scale passenger maglev train seemed impossible to generate in the post-World War I era. Even a smaller mail delivery maglev train seemed unfeasible. Bachelet never gave up on his invention and struggled with its problems without success—losing numerous investors along the way—until his death in 1946 at age 83.

More than two decades later, in 1969, a far more advanced maglev system based on superconducting magnets was patented by James Powell and Gordon Danby at Brookhaven National Laboratory. From there, today's maglev excitement built. Bachelet, it seems, was way too far ahead of his time. TR

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